PRACTICAL TREATISE

ON

PERMANENT BRIDGES,

FOR INDIAN RIVERS:

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SECOND EDITION.

WITH

A DESCRIPTION OF THE

USE OF WELLS FOR FOUNDATIONS,

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PREFACE

(To first Edition.)

THIS little Essay is not intended for the experienced Engineer; its aim being to afford a few simple rules to those who, without the advantages of Professional Education, are frequently called upon to superintend the construction of Bridges in this country.

2. I have confined myself at present to the consideration of Bridges of Masonry as being most generally useful. The subject of Wooden Bridges opens too wide a field, and it cannot be set forth thus briefly. The patterns being of many kinds involve numerous and varying principles. The calculations of thrust, strain, and strength together with joinings, &c. &c., all require professional knowledge, as well as elaborate drawings; thus placing the subject beyond the reach of an elementary Essay. I would recommend an appeal being made to the professional Engineer, when Wooden Bridges of any importance are required. Any Engineer having leisure for such work might publish an Essay on Wooden Bridges, but at present my hands are too full.

3. Throughout this Essay I have used the plainest forms of calculation; thus enabling any Overseer tolerably well acquainted with the rudiments of arithmetical computation, to solve the few problems required.

4. In calculating the thrust of the arch I have omitted the effect of weight of the arch itself in steadying the pier, as the introduction of that element would place the question beyond the reach of ordinary Mathematicians.

5. This small treatise may be useful to Local Committees in the construction of ordinary Bridges. But when large rivers have to be dealt with, the advice of a professional Engineer should be taken, as there are many points of local consideration which will occur to the practised mind alone.

PERMANENT BRIDGES

FOR

INDIAN RIVERS.

SECTION I.

EQUILIBRIUM.

Equilibrium of an arch, is that condition, in which all its component parts balance each other, and are thus enabled to remain at rest without the aid of friction or of cement.

2. In general practice it will be necessary to consider equilibrium merely as it affects the abutments or supports of the arch. This *result* of equilibrium is called "the thrust" of the arch.

3. It is indeed possible so to construct an arch with roadway, that the fabric shall destroy itself: such was the arch built by William Edwards in his second attempt to span the River Taaf. His arch was a semi-circle of 140 feet diameter. The deep haunches being filled in with solid masonry, proved heavy enough to force up the central portion, when of course the whole building fell. This is an extreme case, and could only occur with semi-circular or gothic arches, and of very large span; and such arches may even be rendered perfectly safe by piercing their haunches with openings or by using other methods (hereafter shown) to lighten them.

4. This overloading of the haunches is the greatest danger to which the arch itself is subject, and although it applies with little force to arches of flattish outline, yet modern architects usually reduce the weight upon the haunch, not only with reference to equilibrium, but with a view to decrease the expense of the work.

5. With the above precautions duly observed, and with others of form and thickness, &c., which will be mentioned in their proper places, we may assume as a practical truth that if an arch be properly supported at its feet, it will stand firmly. This leads us to the subject of Section II., viz., "the thrust of an arch."

SECTION II.

THRUST.

Professor Barlow has shown that the lines of thrust in all arches follow certain curves which are of the parabolic class. The exact species of that class being determined by the nature of the loading. The common parabola is however the most generally known, and as its errors are all on the side of safety, it is particularly convenient for our purpose; we may therefore assume this rule :—

RULE. The thrust at any point of an arch is always in the direction of a tangent to some parabola at that point.

2. It is not necessary to exhibit here, the several methods of constructing a parabola: in Appendix A will be found so many of the properties of that curve as are actually essential to our purpose.

3. It is found on comparing the parabola with the circle that the two curves very nearly correspond up to a certain length; and that about 60 degrees of every circle may be *practically* assumed as the upper portion of some parabola; so that by confining ourselves to the use of 60° of a circle we have an arch whose line of thrust may be immediately obtained by drawing a tangent to the circle, or a perpendicular from the radius at its intersection with the circle. (SEE FIGURE 1ST). Where A D B is an arc of 60°, and the lines, A G, B K, perpendicular to the radii, C A, C B, respectively, are tangents to the circle and represent the line of thrust of the arch.*

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* To find C the centre for describing the arc, take the length A B in the compasses, and with centres A and B describe two arcs cutting each other at C.

4. Beyond the extent of 60°, the line of thrust becomes tangent to that parabola of which the arc A D B forms the summit. The method of finding the thrust is shown in Appendix A. In the meanwhile we will see how the arc of 60° can be turned to account in most practical cases.

5. In a segmental arch of 60° the radius is equal to the span—the rise of the arch, or "versed sine" as it is called, is between 1-7th and 1-8th of the span*; which although less than is usual in India is common in Europe.

6. Draw another curve from the same centre C but with longer radius, so as to represent the thick- Fig : 1. ness of an arch of masonry. Then if the feet A and B stand upon rock, we have a substantial arch in equilibrium, or of such a nature, that if each of the arch stones had its sides radiated towards the centre C, and if instead of mortar, something even greasy or slippery were introduced between the joints, the arch would still remain firm.

7. Having ascertained the direction of the line of thrust of the arch, fig. 1 or 2, *i. e.*, the angle that this line makes with the horizon, we can compute with tolerable accuracy the amount of force with which the arch pushes in a horizontal direction against its abutments.

RULE. Find the solid content of the arch from which its weight can be computed. Then multiply half this weight by the cotangent of the angle of inclination of the line

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* The rise or versed sine is found by multiplying the span into the decimal fraction ·1339746. This applies only to the segment of 60°—that fraction being the natural versed sine of 30° to a radius of 1. In other cases it may be found by the rules of Trigonometry or by means of a table of natural versed sines (see Appendix No. 5,) or by the following formula, Versed sine = Radius $- \sqrt{\text{Rad.}^2 - (\text{Half chord})^2}$.

of thrust. The product will be the horizontal thrust of the arch upon *each* of its abutments.

8. To work out the question by lines, so as to avoid the use of Mathematical Tables. Draw any vertical line A B. From A draw A C making the angle B A C equal to the difference between 90° and the angle of inclination that the line of thrust makes with the horizon. Set off on A B from a scale of equal parts, half the weight of the arch in pounds, or cwts., or tons, from A to D; draw D E perpendicularly to A B to cut the line A C at E; then D E applied to the same scale of equal parts will show the horizontal thrust.

Fig: 2.

SECTION III.

ABUTMENTS.

In figures 1 and 2 we have arches striding from bank to bank of the river, the natural soil being supposed to be firm enough to bear the weight and thrust of the arches. But as such soil is seldom found in practice, it becomes necessary to build a mass of masonry called an abutment, at each end of the arch, and these abutments must be founded upon substantial soil.

2. If the line x y (figure 3) represent a stratum of solid soil, clay, rock, or gravel, &c., lying below softer earth, it would appear necessary merely to continue the parabolic curve down to the line x y, but in such a case an injurious strain would be occasioned by the superincumbent mass of earth; it is therefore necessary to give upright abutments, although at a considerable sacrifice of material.

Fig: 3.

3. The springing line of an arch should be kept as low as possible, compatible with safety and convenience, as by such precaution the mass of the abutment is reduced. The height of the springing line is, however, regulated by circumstances. When there is no traffic upon the river, the springing line may be a few inches above the highest possible floods, remembering that the construction of a bridge will frequently raise the floods above any previously experienced.

4. Where rivers are used for navigation, the abutments must be sufficiently raised to admit of towing paths, and the arches must be sufficiently elevated to allow loaded boats to pass freely beneath them.

5. Any unnecessary addition to the height of an arch or an abutment not only wastes material, but causes either an

awkward ascent in the roadway, or the necessity of additional approaches.

6. Having fixed according to circumstances the height of the springing line of the arch, as well as the height of the roadway, it becomes necessary to determine the thickness that must be given to the abutment, to enable it to resist the thrust of the arch. This is a very difficult part of the Engineer's art. Judging from the extraordinary diversity observable in works of the most celebrated architects, it would appear, that scarcely two of them had been guided by the same rules or principles.

7. An abutment may be considered as a compact mass A B C D liable to be moved from its position, either by being turned over on its heel B by the thrust along the line E C, or by sliding on its base A B. When the abutment is lofty, it will be more likely to turn on its heel; when low it will be more likely to slide. Resistance to the first motion is comparatively easy of estimation. Resistance to sliding is a problem involved in much obscurity, for want of a complete knowledge of the laws of friction. We can therefore in this latter case, work only by approximation.

Fig: 4.

8. The resistance of the abutment against *turning* on its heel B is (independently of the earth behind it) represented by the mass of the abutment A B C D multiplied into half its thickness or half A B, but if we suppose the arch and abutments to be composed of the same sort of stone and brick, we may then dispense with solidity and work by surfaces, which will be more convenient.

9. The proposed method of determining the thickness of an abutment to resist the effort of an arch to turn it over, will be best illustrated by an example.

10. The abutment arch of the Hutcheson Bridge, Glasgow, built by Mr. R. Stevenson is a segment of 60 degrees of a circle, the radius and span

Fig: 5.

being each 65′.* The line of thrust which is tangent to the circle at the springing forms therefore an angle of 30° with the horizon. The thickness of the arch is everywhere 3′ 6″. The height of the springing line is 17′, but the abutment is carried up solid to a mean height of 26 feet.

11. To find the thrust of the arch, it will be requisite to allow for the roadway and occasional loading of the arch, and when the material is stone, 18 inches added to the thickness of the arch will cover all. The arch then is 5′ thick, and the length of the half arch is 35′ and $5\times35=175$ is the area of the half arch, this multiplied by the cotangent of 30° or $1{\cdot}732=303{\cdot}1$ is the horizontal force acting upon a lever 17 feet long, therefore the total force to be resisted by the abutment will be $303{\cdot}1\times17=5152$.

12. To find the thickness of abutment necessary to resist the above thrust. Let H be the height of the abutment, and B be its thickness, then $H\times B$ will represent its area; and supposing this, as in the area of the arch, to represent the weight also, we have to multiply it by half the thickness or half B (by the laws of the lever). Therefore $H\times B\times\frac{1}{2}B$ or $\frac{H\times B^2}{2}$ will present the vis inertiæ of the abutment. Now to make this just balance the thrust we have the equation

$$\frac{H\times B^2}{2}=5152$$

From which the value of B will be found to be 19′ 6″ or 19′ 7″ which is almost exactly what Mr. Stevenson has given to the solid part of his abutments.

13. The above thickness enables the abutment just to balance the arch and its load, but it is advisable to have a preponderance in favor of the abutment, this may be

* The mark ′ is used to represent *feet* and ″ *inches*.

given by the addition of buttresses called "counterforts." Mr. Stevenson has made those in the example before us very massive; they are two buttresses 17′ long and 12′ mean thickness, with a horizontal counter arch between them. I should however deem it safe to give four counterforts, each having a length equal to one-third or one-half of the thickness of the abutment, and a breadth equal to one-tenth the breadth of the same.

14. The above example was taken from a number of plans of bridges, merely because the arch happened to contain 60° exactly. The Wellesley Bridge at Limerick corroborates this theory very closely. The calculated value of B being 13′ 10″ whilst the thickness of the solid part of the abutment as executed by Mr. Nimmo is 15′ and there are also three counterforts, each 6′ long and 4′ broad. But on the other hand the Bridge of Jena in Paris being segment of 54′ with a chord of 91′ 6″ and versed sine of 10′ 9″ and where the value of B is calculated at 28 feet, the architect, M. Lamande, has given to the abutment the enormous thickness of 45 feet or half the span of the arch.

15. When the arch is elliptical the line of thrust will be calculated as a tangent to a parabola from the point where the parabolic curve cuts the abutment produced upwards.

16. With reference to the second mode of failure, viz., by the abutment sliding upon its foundation, Mr. Rennie's experiments with roughly dressed granite seem to show that the friction with this stone is somewhat greater than half the weight, and taking into consideration the tenacity of the cement, the resistance afforded by the two, may, with safety, be considered as equal to three-fourths of the weight, if not fully equal to the whole. However limiting the effects to three-fourths of the weight of the abutment. We will suppose the following case:

Let A D B be a segmental arch of 60° A B being 100', D d 5 feet. The rise or versed sine will be $13\frac{1}{2}$ and the surface of roadway may be 2 feet above the key-stone, so that the total height of the abutment will be $13\frac{1}{2}+5+1 = 19\frac{1}{2}$ feet. The thrust falling at the foot of the abutment, it is plain that it will be more likely to slide upon its base than to turn over upon its heel. The force or horizontal thrust will be $6\frac{1}{2}\times 50\times$ cotangent $30° = 576$; and the equation of equilibrium will be

Fig. 6.

$$H\times B\times \tfrac{3}{4} = 576.$$

or

$$B = \frac{576}{H} \times \frac{4}{3}$$

and as H = 19 5, B will equal 39 feet nearly. Some little allowance may be made for the sake of safety.

18. In figure 7 where the rise is one-fifth of the span the value of H is 26, and this reduces the value of B to 28.

19. That the thrust of an arch is exceedingly diminished by the tenacity of the masonry when consolidated was shown by an accident which occurred very recently with an old bridge of considerable size. The valley which is extensive is crossed partly by the bridge and partly by a viaduct pierced at intervals by small arches.

20. In the rains of 1842 one end of this bridge, 130 feet, consisting of six small arches standing on boxwork 9' deep, was undermined, together with a portion of the causeway. The waterway being considered insufficient, it was proposed to substitute a set of arches, varying from 30 to 21 feet span, in place of the injured portions of the bridge and causeway. The overseer in charge, by some strange oversight, proceeded to dismantle the injured arches, without taking any precaution towards supporting the next sound arch, (a semi-ellipse of 30' span and 7' versed sine) which was thus left abutting on a pier 6 feet thick and 11 feet high: such an abutment was much too weak, and

under the thrust of a fresh arch would have been overturned, but the old arch merely opened a little underneath the key-stone, and threw the pier slightly out of the perpendicular. A heavy buttress was then applied, until the new companion arch could be turned (a semi-ellipse of 31 feet span). On the centering of this new arch being struck, the pier resumed its original position and the crack of the old arch closed up.

21. This example is instructive inasmuch as it shows that one-fifth of the span is not sufficient for the *abutment* of an elliptic arch of similar span, rise and supports; and these proportions are very commonly used in regard to piers.

22. It is not recorded that any opening or crack took place between the springing and the crown of the above arch, which, according to some theoretical writers, ought to have been the case. However, it is by no means certain that such an intermediate crack did not take place.

23. I have omitted from the calculations, all consideration of the steadiness imparted to the abutment by the *vertical* pressure of the arch. This element would render the subject too abstruse for the ordinary builder. Nor do I believe that it has ever been considered *practically*.

SECTION IV

PIERS.

A pier is an abutment supporting the feet of two instead of only one arch: it then ceases to be an "abutment," as the horizontal portions of the thrust of the two arches *abut* against and balance each other, leaving only the vertical or perpendicular portion of the thrust (which is simply the weight) to be borne by the pier.

2. Now the weakest material of which a masonry bridge is constructed, viz. brick, is so strong in resisting a crushing force or weight, each square foot being estimated as capable of bearing about 80,000 lbs. weight or 35 tons, that a pier 2 feet thick would (without other considerations than that of the mere weight) suffice to support the feet two arches of 200 feet span each, and two feet thick or deep.

3. In practice, however, arches meeting on a pier do not always counterbalance each other completely. The pier, if very thin, would be ricketty and liable to be split or bent by the load, although the bricks themselves would not be crushed: it is therefore usual to give a much greater thickness to piers than is absolutely necessary for supporting the load.

4. Some Engineers consider it necessary that a pier should be strong enough to act as an abutment to the other arch in the event of one arch being broken. But this would generally require the pier to be one-third or one-fourth of the span, and this would interfere too much with the waterway. One-fifth and one-sixth of the span are both practised in India, and they give a light and elegant pier. This thickness is measured at the summit of the pier.

5. It is a good practice to build piers with a slope or "batter" as it is called, thus making the thickness greater

at the foot of the pier. This not only imparts steadiness to the pier, but causes it to oppose a greater surface against the soil, rendering it less liable to sink into the soil. This slope or batter need not exceed 1 in 12. With low elliptic arches it is common to give a considerable batter, but in the form of the curve, (vide figure 8) which gives a very elegant appearance, but it reduces the waterway and is only allowable on particular occasions.

Fig: 8.

6. In running streams of any magnitude it is advantageous to shape the ends of the piers into cutwaters, for the purpose of passing the water through the arch with as little turmoil as possible. The best form for such purpose would be that of a very sharp wedge, but this would be weak in itself and dangerous to boats. A very good form is obtained by describing arcs from each corner of the pier with a radius equal to the thickness of the pier. In small bridges or where the current is slack, it will be sufficient to describe semi-circles on the ends of the piers as diameters.

Cutwaters.

Fig: 9.

7. Piers should be built in a very solid manner, and with very fine joints, to obviate settlement.

Fig. 10.

8. The summit or head of a pier should rise above the highest flood level.

SECTION V.

THE ARCH.

There are only two curves well adapted to bridge purposes, viz: the segment of the circle and of the ellipsis or oval. The first is the simplest, but a constant repetition of it would be tedious to the eye, which requires variety, and this is afforded by the ellipse and its modifications.

2. There are many ways of drawing an oval, some of the most useful of which are shown in Appendix B; but we will here see how the segment of 60° may be converted into an oval, so nearly resembling the true ellipse, as to be hardly distinguishable from it, even on measurement.

3. Draw the arc A D B as in figure 1st, draw the perpendicular radius C D and upon it set off D E equal to about one-fifth of the span A B. Through E draw H E I parallel to A B making E H, E I, each equal to half A B. From the points x and y taken at about one-fourth of the half arcs A D, B D, draw by the aid of the eye the curves x H, y I to complete the oval. This is a very graceful curve and has a very convenient rise. Its thrust is exactly the same as in Figure 1.

Fig: 11.

4. To obtain the back or *extrados* as it is called (the underside being called the *intrados*). After having determined the depth of the key stones D d, take C d as radius, and from centre C describe the arcs K d L.

5. The joints of the *voussoirs* or archstones are all drawn towards the centre C.

6. The form of the arch may be varied by making the versed sine D E greater or smaller in proportion to the span.

7. One of the most graceful arches in Europe is a semi-ellipse, whose rise is less than one-sixth of the span; it is built of marble. The arches of the town bridge on the canal at Kurnaul, built by Colonel J. Colvin of the Bengal Engineers, are of similar proportions, and are built in brick. Very flat curves require care and attention in setting the joints accurately; but care and attention should be bestowed upon every arch however simple its form.

8. Gothic, Mahommedan, and other pointed arches are not well suited for bridges, as they require a more than convenient rise, besides, being mechanically objectionable.

9. *Thickness of arch*—or the depth of the key-stone. Authorities and examples differ very much, in regard to this fundamental. Key-stones which generally denote the depth of the arch at the crown have been actually constructed from 1-10th to 1-47th of the span. If it were necessary to guard against dead weight or thrust simply, the depth of arch actually necessary would be very small; but as vibration is one of the most dangerous enemies of a bridge, it becomes expedient to give such solidity as to reduce this action within safe limits. In large arches of stone 1-30th of the span or thereabouts is a favorite depth of key-stone with modern architects; but this would be much too small in small brick arches of 30′ and 40′ span. Brick being lighter than stone, and the compressive force of a small arch being much less than that of a large one, the equilibrium would be more easily disturbed by a passing load. For brick arches of 40 and 50 feet span 1-18th of the span will be found a good thickness, for 30 feet spans 1-15th, for 20 feet spans, 1-10th and for 10 feet spans 1-5th. It is false economy to allow less than 20 or 24 inches to the smaller bridges or culverts.

10. *Turning the arch.*—Preparatory to turning the arch it is necessary to provide a form or *centering* on which to lay the bricks or stones of the arch itself. In Europe, centerings are made of timber, but in this country where timber is generally scarce, and the spans of bridges usually

small, pillars of mud-cemented masonry are built between the piers or abutments, and on these may be laid either a wooden frame coinciding with the form of the intrados of the arch, or a form of brick and mud work may be substituted. Vide figures 12 and 13.

11. Such centres will only be applicable to arches which can be turned with certainty before the periodical floods take place. Where this is not possible, piles must be substituted for the pillars; or *centres* of timbers must be made, which will stand by resting upon the piers. These latter require considerable mechanical skill and are very expensive. It would be impossible in a work like this to go into all the varieties of those frames. An experienced Engineer should always be applied to when such centres become necessary.

12. Upon the moulded surface of the centre, the arching bricks are laid, commencing at the haunch and taking care to make the two sides approach equally towards the centre, and to leave a space at the centre just sufficient to receive one brick as a key-stone. This brick or key should be inlaid with finely ground mortar and be driven home with a few light taps of a wooden mallet: care must be taken not to use too much force or the arch will perhaps start near the haunches.

13. *Joints.*—All the joints should be drawn at right angles to the curve of the parabola; but where only 60° of a circle are employed, the bricks are all radiated to the centre of the circle. When the span is 20′ and upwards it will be needless to dress each brick to the form of the arch. It will suffice to make the joints as small as possible, recollecting that the bricks should be in actual contact; the cement merely filling up their inequalities.

14. When the arch is keyed or completed, the centering may be removed. This operation should be performed by excavating the earthen mould from below the centre of the arch, working thence towards the haunches, and by

equal gradations on either side of the centre, otherwise the arch might settle unequally and be strained. When a wooden framing or *centre* is used, the whole is disengaged at once from the under side of the arch, by simultaneous strokes on the heads of a series of wedges on which the framing rests.

15. *Bonding.*—As far as 40 feet a very simple mode of bonding the masonry of an arch has been found successful. The bricks are all laid on edge with the centering, and are carried round from pier to pier in concentric rings. Horizontally they break joint across the arch. Arching of this pattern is hardly more expensive than common wall work, but it is found to be inapplicable to very large spans.

16. The most usual mode is that of the common bond. One brick is laid on edge to the centering, its length laying in the direction of the breadth of the arch; the next brick is placed with its end upon the centering and its length in prolongation of the radius; thus breaking joint on the thickness as well as on the breadth of the arch.

17. *Cements.*—One of the best cements ordinarily to be obtained in this country is made of one part stone lime, and two parts fine soorkhee. *Bujree* or gravel being seldom fine enough for arch joints. The lime should be fresh and caustic; the soorkhee should be made of the soundest bricks. The two ingredients should be mixed and ground dry under a chuckee or grinding stone; and should then be slaked with just sufficient water to make them into a paste. If fine bujree be used, the same mode of treatment is to be observed. The quality of the cement depends greatly upon the lime being slaked from its caustic state, whilst in contact with the gravel or soorkhee.

18. *Haunches.*—To relieve the shoulders or haunches of the arch from unnecessary weight, as well as to save material, thin longitudinal walls, called spandrell walls are built

at intervals, extending from the abutments nearly to the centre. Their summits support either slab stones for covering the intervals, or small vaults of masonry.

19. These walls may be $1\frac{1}{2}$ or 2 feet in thickness: their intervals, where flags are used to cover them, must depend upon the size of the stone procurable. When vaulting is used the intervals may be $3\frac{1}{2}'$ or $3'$; the outer walls in this case should not be under two feet.

SECTION VI.

ROADWAY.

On roads of great traffic, and when the bridges are small, they should be the full breadth of the road. But when bridges are large this would cause them to be too expensive; they should not, however, be less than 24 or 25 feet in clear width of roadway between the parapets.

2. A flat or level roadway is the most convenient, but where a rise is necessary the slope should not exceed *one* in thirty-five (1 in 35), which means one foot of rise to 35 feet of base.

3. Above the extrados or back of arch there must be laid a course of bricks on edge fixed in mortar, and over this a layer of 6'' of metal (beat down from 9'') this surface should be well drained by means of outlets through the parapet walls.

4. The roadway should always be guarded by parapet walls, varying from 3 to 5 feet in height and from 1½ to 2 in thickness according to the nature of the bridge. These walls are continued with a curved splay outwards from the ends of the bridge to form proper entrances or approaches, and are there called the *wingwalls*.

SECTION VII.

TREATING OF THE FOUNDATION FOR BRIDGES, ESPECIALLY IN INDIAN RIVERS.

1. Hitherto I have considered the abutments and piers as standing upon solid soils, their bases being spread out to give a better footing; but in India it too frequently happens, that, this precaution is not sufficient. The general character of the earth's crust, in India, is a superstratum or upper layer of clay, varying in quality by its mixture with sand or vegetable mould, and varying in thickness from 3 feet to 20 or even more, with a substratum of sand to great depths; but generally containing layers (sometimes thin, sometimes thick) of clay or kunkury clay, lying at various depths below the surface of the sand.

2. When rivers run in the upper stratum of clay without cutting through it, their streams will generally be found to be sluggish, having little slope, and running across or obliquely with the general line of drainage. With such streams, it will be necessary, merely to sink the footing of the piers and abutments a few feet below the bed of the stream. But where the clay has been cut through, exposing the sand, it becomes necessary to take further precautions for fixing the feet of the piers and abutments.

3. Sand when free from the action of running water or other disturbing forces is, by no means, a bad foundation; it is superior to many kinds of clay; but in the bed of a river, and under even the most gentle current, it is liable to be moved; and is therefore quite unfit for the footing of piers, &c., and it becomes necessary to seek artificial means of securing the foundations.

4. With small bridges and where the current is not very strong, and where the natural waterway has not been

much diminished by embankments, it is sufficient to support the bridge upon "boxed foundations." These are formed by making large boxes of wood, of the shape of the pier or abutment, but about 9″ or 12″ larger each way as to length and breath. The boxes have neither tops nor bottoms, their sides vary in height from 6 to 10 feet according to circumstances. These boxes are driven into the sand by scooping from the interior, and they are then filled with rubble masonry. Upon this masonry the piers and abutments are built.

5. Beyond the depth of 10 or 12 feet, it is better to use wells or blocks of masonry.

6. Wells are familiar to the Natives of India, who have used them as foundations for many centuries. The class called well-sinkers are very expert. Almost any *raj-mistree* will lay off the wells of a foundation. It is therefore needless to enlarge upon the subject here. When a cutwater is used, care must be taken to have it also supported by a well or part of a well.

7. "Blocks" are a variety of the well foundations. In this case a frame of stout wood well joined is made in the shape of the pier or abutment or of a portion of one, being a little wider each way. Upon it is raised a mass of masonry, conforming to the shape of the wooden frame or *ny-chuck*.* The masonry is pierced by wells, varying from 3′ to 5′ in diameter and placed at various distances: but the largest wells should not be more than 3 feet apart. When the pier or abutment is large, it may be divided into two or more portions. These masses are driven down after the manner of well sinking; they are capable of being well loaded, and they may be sent downwards with great nicety, and are not so apt as wells are to topple over. They are more expensive than wells but are much firmer.

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* Called also *neem-chuck*.

8. Blocks may be laid at distances of 8 and 10 feet, the intervening spaces being covered with arches. This is economical in large works.

9. A table is given of the rates and times of block-sinking, compiled by Major W. E. Baker, of Engineers, from the day-books of work at a canal bridge.

Table 1.

10. The following remarks apply equally to wells or blocks.

11. These foundations may be supported in two ways, either by driving them down to the solid soil,—clay or kunkur, or rock,—or they may be suspended, as it were, in the sand, by mere friction, the force of which is very great in sand; so much so, that, beyond the depth of 40 feet or so the labor of sinking the masonry becomes excessive, and unless the head be well weighted by extraneous loads, there is great chance that the lower portions will drop away into the hollow formed by the excavators; but by heavily loading the summit, wells have been driven 50 feet through sand.

12. If the river's bed were not disturbed to any great depth by the action of the water, there would be no necessity for sinking the wells very deep; friction alone would suffice to uphold them; but Indian rivers have this peculiarity, that during eight months of the year they occupy very narrow channels, and during the rest of the year they flow with broad and rapid streams, overflowing the country, sometimes for miles on either side.

13. It would be too expensive to carry a bridge over the whole or even one-half or one-third of this flood: it is therefore usual to embank the greater portion of the low ground, with a stout mound of earth, restricting the river to such a channel as we may have the means of bridging.

14. Such reduction of the waterway causes the water to rise in a heap above the bridge, and this causes a rush or rapid through the arches, sufficient to tear up the sand to a great depth; so that shallow foundations would be rooted up.

15. That the uprooting force of these rapids extends to great depths, will be shown by the following facts.

16. In 1831 a masonry bridge of three arches, each of 60 span, was built over the "Neem Nuddee," on the road between Futtehgurh and Koel. The river there runs in a wide shallow valley, and for eight months in the year has no stream, being nearly dry; it takes its rise below Boolundsher about 35 miles above the bridge, and as it is hemmed in between the Ganges and the Kalee Nuddee, it cannot drain a greater area than 150 square miles; yet in the rains of 1838, the floods came down with such violence, that they rose above the crowns of the arches and then excavated the soil below the foundations until the whole mass, excepting the abutments, fell into the gulph.

17. The arches were flat ellipses springing low, and with splayed piers, described in Section IV. Para. 5. The foundations were wells, sunk to the depth of 20 feet, and were supposed to rest on good clay.

18. The eastern Kalee Nuddee takes its rise in a swamp close to Kotowlee, Mozuffernugger district, and about 25 miles north of Meerut. It is like the Neem Nuddee above described as to its valley, and its dry weather appearance. The slope of the bed does not exceed 14 inches per mile. The river drains an area of about 250 square miles.

19. Over this river and on the Gurhmooktesur Road close to Meerut was built in 1840 a masonry bridge of three arches, each of 25 feet span, supported on wells running down $22\frac{1}{2}$ feet below the river's bed, and supposed to rest upon a strong stratum of clay mixed with kunkur.

20. In the rains of 1842 a heavy flood occurred; the water rose 8 feet perpendicularly. It did not reach the crowns of the arches, but it rushed with such violence as to scoop out the sand to a depth of 23 feet, or 6 inches below the footing of the wells. The wells dropped perpendicularly 6 inches and there stood (it is supposed) on the real kunkur bed. The bridge did not fall but the arches split into many fissures. On attempting to remove the arches, the whole went down into the pool. Had this pool been filled with sand previously to this attempt, the foundations might have been saved, but would hardly have been trustworthy.

21. Too much caution can hardly be used, in ascertaining, by personal inspection, whether the wells have reached a solid stratum. Native workmen anxious to get this laborious part of the operation over, generally try to persuade the architect that the wells are firmly footed. I think it highly probable that the wells of the Kalee Nuddee Bridge had been stopped just six inches short of the solid soil, and that 6″ more of sinking would have saved this useful bridge.

22. The piers of a suspension bridge of 400 feet waterway had been completed on the Hindun River near Dehli, and the abutments had been connected with the high bank, by an earthen causeway measuring a mile, from end to end, when, in the rains of 1844 the waters rose 11½ feet, and scooped out the sand from the eastern end to the depth of 25½ feet. The pier at which this occurred stands upon wells, as do all the rest, but the wells of this one after having been driven to the depth of 34 feet, moved with so much difficulty as induced the architect to stop work, leaving them supported by sand alone. Great apprehension was entertained regarding this pier whose wells were actually bare of all but water, to the depth of 25½ feet. They remained firm, supported by the friction upon 8½ running feet of their lower extremities. Sand bags were thrown in

and before the occurrence of another flood the pool was filled up.

23. In Europe, wooden piling is used to a considerable extent, in securing foundations, but it is not often applicable in this country, as it is necessary to the durability of the piles, that they shall be completely covered by water at all times, and in large rivers, where they might be so submerged, the great depth of sand, sometimes 50 feet, is beyond the reach of the largest timbers procurable in the Upper Provinces; nor could the pile be driven to that depth in some cases. Timber piles might be scarfed certainly, but they would be more expensive than wells, which are nothing more than piles of masonry.

Piles.

24. Piling, however, is often used as an auxiliary, in defending the feet of causeways, and the wing walls of bridges, also in protecting the *curtain* walls where flooring is given below the arches; but all these are on a small scale, and the subject requires little notice. I will merely add that in driving piles, it is better to use a heavy weight with a short drop, than a light weight with a long drop. By the former the work is more speedily executed and the pile heads are less injured. Also that when driving piles, in sand, especially quick sand, the blows should be given as quickly as possible. The moment the pile ceases to vibrate, the sand settles around it, and lessens the effect of the next blow: the longer the intervals between the blows, the less will be the effect of each. A pile half driven in sand and left for any length of time will be, sometimes, found immoveable.

25. Instead of using piles or wells or other deep foundations, the piers and abutments of moderately sized arches are sometimes supported upon inverted arches as in figure 14. These arches, by distributing the pressure over a large area, enable a bad soil to resist the weight of a bridge, which it could not do were the

Fig: 14.

pressure concentrated in the narrow areas of the piers and abutments.

26. Such a foundation is only applicable where the soil is not liable to be moved, for it is evident that if the soil were washed out from below the centre, the arch at that part would very probably drop down.

27. Inverted arches will sometimes save a weak clay soil from being cut by a rush of water through the bridge. In this case there should be curtain walls some few feet deep drawn across the opening from pier to pier, to prevent the arch from being undermined. A row of piling is sometimes given instead of the curtain wall, but the wall is the best. Sometimes both are used, viz. a curtain wall resting upon piles.

28. In large bridges where there is generally to be found water at the very footing of the piers, it would be extremely difficult to turn an inverted arch, and as the soil in such cases is generally sand, the arch would be unstable.

29. In cases where the waterway of a large bridge is found to be dangerously small, the foundations are sometimes secured by a flooring of masonry. This flooring should be four or five feet thick, and besides lying between the piers, should extend 20 feet beyond them both up stream and down. The outer edges being guarded by sunk curtain walls, if possible, or by rows of piles, sheet piling (stout planks of wood would be the best if procurable at moderate cost). It is better to avoid the necessity for these costly additions, by allowing a sufficiency of waterway in the original design.

SECTION VIII.

ON THE PROPER WATERWAY FOR BRIDGES.

The most difficult part of an architect's task is, very often, to determine the amount of opening or waterway to be given to a bridge. When the banks are well defined and the river does not overflow, then the question is comparatively easy; but when, as with our Indian rivers, the dry weather supply is a mere rivulet, or perhaps nothing, and the rainy season supply a flood, spreading over the country; then the question becomes one of very intricate calculation, inasmuch as it is difficult to determine what portion of the water is moving, and what is mere back-water. It is seldom also that the architect has opportunities of seeing the highest floods; therefore he gathers his accounts from others; or even if he should happen to witness a flood, he may not happen to have the means of measuring the sections and velocities.

2. As however an approximate calculation is better than mere guess, I will show a simple mode of making an useful estimate of the quantity of waterway that should be allowed.

3. Let A B represent the flood-line of a river; it is plain that if we measure the areas of each compartment x, y, z, and s, and ascertain with what velocity the water is moving through each, we shall know how much water actually passes by in a given time, say a minute or a second.

Fig : 15.

4. Now as water flows on account of the slope in the river's bed, if we know the velocities caused by certain slopes, we can calculate what amount of opening must be given to a bridge, to allow the whole of the water of the above Section, to pass under the bridge at its natural velocity, and

so avoid all that *heading up* which is found so destructive. That amount of opening would be the *safest* one.

5. The *safest* width of opening would, in many rivers, be inconveniently great: we are therefore obliged to run some risk by confining the floods to narrower bounds, and this causes a heading up or *afflux;* and in proportion to the perpendicular height of this afflux, so will the velocity be.

6. Table III. shows that sand is moved by the smallest velocities, even so little as six inches per second or about one-third of a mile per hour, therefore the beds of our rivers must be continually moving, and the question becomes "to what depth does this movement extend under certain velocities of current?"

7. Experience alone is our guide in replying to the above question, but I regret to say that until very lately, little or no attention had been paid to the subject. From certain data which need not be mentioned here, I calculated the flood mentioned at paragraph 22, Section VI., to have been about 11 feet per second, and as the effect of this velocity was to scoop out the sand to a depth of 25½ feet, it is plain, that any velocity approaching to 11′ per second must not be risked, under ordinary circumstances. I consider a velocity of 5 or 6 feet per second to be dangerous to bridges whose foundations do not rest on firm soil, or which are not carried to very great depths, and this velocity is caused by an afflux or heading up of only 6 inches.

8. The above may appear a small velocity to cause so much damage. Nature has however afforded us some clue even in this difficult computation. Captain Sharp, in boring the bed of the Jumna at Agra, came upon broken *bricks* at a depth of 23 feet, and this can only be accounted for by supposing, that the bed has been disturbed to that depth by the natural current of the river. Captain Sharp, roughly guesses the *surface* velocity of the Jumna at Agra, to be 8 feet per second at high floods, but from certain data,

I do not calculate the *mean* velocity to be more than $5\frac{1}{2}$ or 6 feet per second, and this velocity is caused by the confinement of the flood between two bold banks only 1,300 feet apart. The velocity of the greatest flood at Dehli is, probably, much less than 6′ per second.

9. In table No. II. is given the amount of afflux caused by obstructions in the river's course. In Table No. IV. is given the velocities due to those affluxes. If therefore the section of the river and its velocities can be accurately measured, the amount of waterway in the bridge, so as not to cause a greater velocity than 5 feet, nor a greater afflux than 5″, can be at once taken from those tables.

10. I have said that very few architects ever have the opportunity of seeing the river in question at its floods; it may then be asked how the velocity and discharge can be ascertained.

11. Determine by enquiry the height of the highest flood ever known, and correct the information, if possible, by flood marks.

12. Take an accurate section of the river's bed perpendicularly to the course at the site of the proposed bridge, and calculate the area contained between the highest flood line and the bed. Do the same at points one mile above and one mile below the proposed site of bridge.

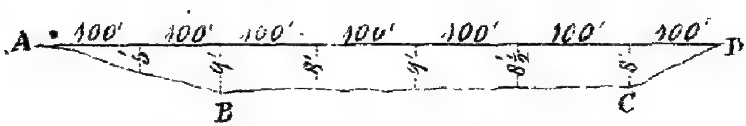
13. Measure the length of the undulating line of the river's bed (in each cross section) and divide the area by this length, the quotient will be what is called the *Hydraulic mean depth,* which will be found to vary very slightly from the common mean depth, in most Indian rivers.

14. Add together the three mean depths so found, and divide by three, the quotient will be the *mean* of the three "Hydraulic mean depths" to be used in the calculations. Write it in inches.

15. Ascertain, by means of a levelling instrument, the difference of level between the upper and lower section; that is, the amount of slope in the river's bed for two miles; and write it down in inches.

16. Multiply the Hydraulic mean depth in inches, by the difference of level just found (also in inches), and take the square root of the product, which will be the surface velocity of the current per second, in inches. Nine-tenths of the surface velocity may be taken as the "mean velocity."

17. Knowing the area of the section, (the mean of the three areas should be used), we can by reference to the Table No. II. ascertain the afflux which will be caused by damming up one-third or one-fourth, &c. of the natural area, or waterway, thus:



The area of this section is 4600, and if the length of the line A B C D measure 710 feet; then $\frac{4600}{710} = 6{\cdot}48$ feet, the Hydraulic mean depth.

18. Let us suppose that the two other mean depths were 6·8 feet and 6·1, then $\frac{6{\cdot}8 + 6{\cdot}1 + 6{\cdot}48}{3} = 6{\cdot}46$, which is the *working* Hydraulic mean depth; and in inches it will be 77·52″.

19. Say that the difference of level between the upper and lower sections is 30 inches: then,

$\sqrt{77 \cdot 52 \times 30} = 48 \cdot 2$ inches, which is the surface velocity, and $48 \cdot 2 \times \frac{\cdot 9}{10} = 43 \cdot 38$ inches, or 3·6 feet, the mean velocity in feet, per second.

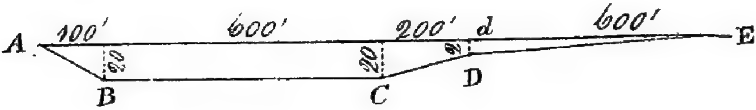
20. Say that we had proposed to have a bridge of three arches, each of 50 feet span, springing at a height of 6·46 feet above the bed of the river, then $3 \times 50 \times 6 \cdot 46 = 969$ represents the area of the waterway; and this is between two and three-tenths of the whole mean area of sections; therefore the *obstruction* will be equal to 7 or 8-tenths.

21. Now enter Table No. II. with the velocity 4 feet, which is nearest to 3·6, and run the finger along until you come under the column 7-10ths, and you will find the afflux to be 3·2755 feet; and in the next or 8-10ths it is marked as 7·7750 feet; take the mean and call the afflux 5·5, and on referring to Table No. IV. you will find the corresponding velocity to be between 17 and 19 feet per second; which would tear up all but rock.

22. To find the waterway corresponding to the safe afflux of 5 inches, giving a velocity of 5·1 feet per second (see para. 9, page 29), enter Table No. II., with velocity 4 feet per second, the assumed mean velocity of the river before meeting with obstruction, and opposite to it, the afflux 5 inches (·4166 feet) would be between the third and fourth columns,—shewing it to be due to an obstruction of between 3-10ths and 4-10ths of the sectional area: the waterway, therefore, must be equal to 6-10ths of the area, and if the spring of the arches is 9 feet high, $\frac{4600}{9} \times \frac{6}{10} = 306$ is the length of the waterway required: and if 50 feet arches are preferred, it will require six of them instead of three.

23. I have shewn the general principle for ascertaining the proper opening for a bridge, but as all Hydraulic formulæ have been computed for rivers of tolerable regularity of section, the application of the above principles to

our Indian rivers, will require modification. If we suppose a river to have the following Section:



the area of the whole is 15,800 square feet, the Hydraulic mean depth is 10·5 feet or 126 inches. Suppose the fall in two miles to be ten inches, then $\sqrt{126 \times 10} = 36''$ or 3 feet, and $15{,}800 \times 3 = 47{,}400$ is the discharge in cubic feet per second, according to the general rule.

24. But if we take the section in two parts, viz. A B C D *d* as one, and the triangle E D *d* as the other, and calculate them separately, we shall find a considerable difference between this result and that of our first computation, thus:

25. The area A B C D $d = 15{,}200$, the Hydraulic mean depth is 16·6 feet or 199·2 inches: then $\sqrt{199 \times 10} =$ 44·62 inches, or 4 feet nearly; and $15{,}200 \times 4 = 60{,}800$ cubic feet per second as the discharge for the one portion alone.

26. The triangular portion has an area of 600 square feet: the Hydraulic mean depth is 1 foot or 12 inches; then $\sqrt{12 \times 10} = 11$ inches nearly the superficial velocity. And $600 \times \frac{11}{12} = 550$ cubic feet the discharge per second: therefore $550 + 60800 = 61{,}350$ is the discharge instead of 47,400, as in the first computation.

27. I have used the superficial velocities in these illustrations, but in practice the mean velocities should be used.

28. The architect must use his discretion in calculating different rivers. Some may be taken by the first rule; others may require three or more separate computations on divisions. The calculations belong to plain arithmetic, and with this view I have selected the formulæ of Mr. Eytelweir, a German Philosopher, in preference to those by the French Academicians, which are rather abstruse; and are not, I think, one jot more accurate when applied to open rivers. Persons desirous of studying the subject more deeply, would do well to consult the *Encyclopædia Britannica*, or Robinson's *Mechanical Philosophy*.

SECTION IX

GENERAL OBSERVATIONS.

Position of a Bridge.

Site.—The general situation of a bridge will be determined by the line of road which it is intended to carry; but its exact site should be selected, as much as possible, in conformity with the following views.

1. Bold banks are to be preferred with Indian rivers, as involving less expense in the matter of causewayed approaches, and as rendering the direction of the stream more certain.

2. The middle of a straight reach (with regard to flood stream) should be selected; as, in bends of a river, one bank is under continual erosion, therefore the abutment on that bank would be in danger of being turned by the current.

Number of Arches.

As a general principle, it is better to make few arches of large span than many arches of small span; as involving less trouble in the foundations, and as affording freer passage for floods. Thus a river is more obstructed by two arches of 25 feet each than by one arch of 50′ span.

Ornament.—Solidity and durability should on no account be sacrificed to appearances. Thus, when brick work is used, the parapets should be formed of plain panelled masonry, in preference to balusters of pottery.

The arch itself should always be indicated or relieved in some manner, otherwise the opening will look like a hole cut in a wall. In brick work, this may be done by projecting the arch face 4″ or 6″ beyond the surface of the rest of the masonry, when it may be chiselled into voussoirs or into fillets.

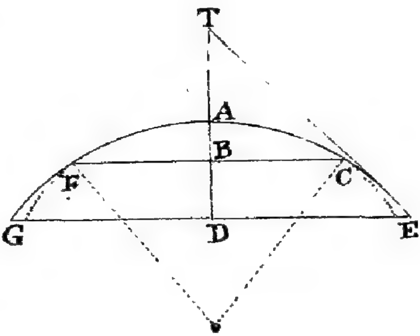
Pillars or pilasters with entablatures, have been exploded by good taste.

APPENDIX.

APPENDIX A.

THE PARABOLA.

In the application of the parabolic theory to the thrust of an arch as in Section II. we always have, as known quantities, the upper portion of the parabola, viz. the arc of 60° F A C, and the



ordinate B F or B C; which is half the radius by which F A C was described; and the absciss A B, which is the rise or versed sine of arc F A C, and is found by multiplying the radius into the decimal fraction ·1339746. Then to find the ordinate to any other absciss A D, the following proportion is used:

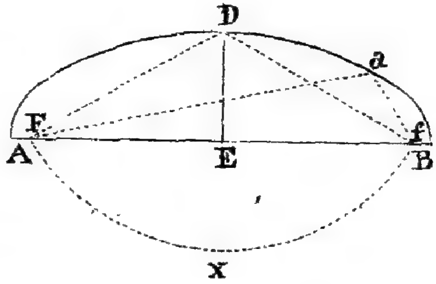
$$AB : AD :: BC^2 : DE^2$$

consequently $DE = \sqrt{\dfrac{AD \times BC^2}{AB}}$ and to obtain the line of thrust at the point E upon B A prolonged upwards, set off A T = to A D and draw T E which will be the line of thrust required.

APPENDIX B.

CONSTRUCTION OF OVAL CURVES.

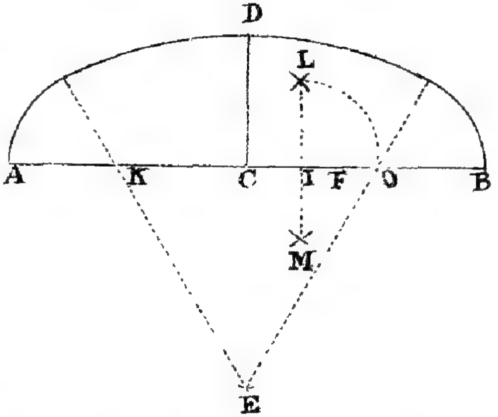
To construct the true elliptic curve by means of strings.



Set off A B equal to the larger diameter, of which E is the centre. Draw E D perpendicular to A B, and equal in length the proposed rise of the arch. Take A E or E B in the compasses, and with one foot on the point D, sweep the arc F x f, cutting the diameter in the points F and f which are called the *foci*.

Take a string equal in length to twice F D or f D, (that is, equal to A B); fix its ends at the *foci* F f and with a point (keeping the string always fully tight) describe a curve which, if well managed, will be a true semi-ellipse.

To describe an oval curve resembling the ellipsis.



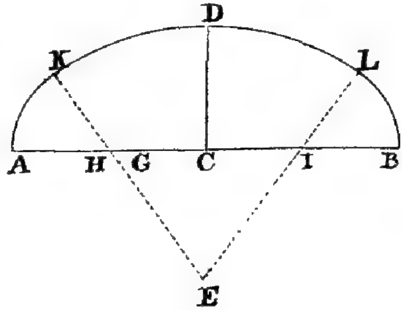
Let A B be the longer diameter, and C D the rise or height of the curve above the centre C. From B set off B F = C D. With C F in the compasses, and from the centres C and F describe small arcs cutting each other above and below the diameter: connect their points of intersection by a line L M, cutting the diameter in I; with I L as radius, and I as centre, sweep the arch L O. O will be the centre of the small circle, for completing the oval. Set off C K = C O.

With O K as radius, and from the centres O and K sweep arcs intersecting at the point E, which will be the centre of the larger circle for forming the upper portion of the oval.

Each of the three arcs contains 60° of a circle.

When the rise of the arch is less than one-fourth of the span, this rule produces an unsightly curve. In such cases the reader is recommended to adopt the mode shown in Section V. paragraph 3, or to describe the curve by means of strings.

To describe an oval curve resembling the ellipse when the rise is equal to one-third of the diameter or span.



Let A B be the span and C D the rise at centre; equal to one-third of A B. Set off half of C D from C to G, divide C G into three equal parts, and add one of those parts on towards H.

Make C I = C H.

On D C produced downwards set off C E equal to C D. From E draw the lines E H K, E I L, then with radius E D sweep the arc K D L, and with radius K H and centres H and I, describe the small arcs K A, L B.

APPEN

TABLE

TABLE of DAILY PROGRESS and COST in undersinking the BRIDGE, communicated by CAPTAIN W. E. BAL

Feet.	*Front Abutment Blocks 12' 3"×10' 0", with 4 shafts in each.*				*Total.*	*Averages.*	*Cost of sinking 100 square feet of Block, in Nos. 1, 2, 3 & 4.*			
	1	2	3	4						
	DAYS.	DAYS.	DAYS.	DAYS.	DAYS.	DAYS.	Rs.	As.	P.	
1	0·5	0·5	0·5	0·5	2·0	0·5	1	7	8	
2	0·75	0·75	0·5	0·5	2·5	0·65	1	13	7	
3	0·75	0·75	0·75	1·0	3·25	0·8125	2	6	6	
4	2·25	1·75	0·75	0·75	5·25	1·3125	3	14	2	
5	0·75	1·0	1·0	1·0	3·75	0·9375	2	12	5	
6	0·75	0·75	1.	1·	3·5	0·875	2	9	5	1
7	0·75	1·	1.	1·	3·75	0·9275	2	12	5	1
8	0·75	0·75	0·75	0·75	3·	0·75	2	3	6	2
9	0·75	0·75	1·5	1·	4·	1·	2	15	4	1
10	1·	0·75	1·	1·5	4·5	1·0625	3	2	4	1
11	1·	0·75	1.25	1·5	4·5	1·125	3	5	4	2
12	2·	1·25	2·	1·75	7·	1·75	5	2	11	2
13	1.25	1.	1.5	2·	5·75	1·4375	4	4	1	1
14	2·	2·	2·	2·	8.	2·	5	14	9	[illegible]
15	2·	2·	2·	2·	8·	2·	5	14	9	[illegible]
16	2·	2·5	2·	2·	8·	8·125	6	4	8	[illegible]
17	1·5	3·	2·	2·25	8·75	2·1875	6	7·	8	2
18	2·5	3·	3·	2·25	10·75	2·6875	7	15	4	4
19	2·5	3·	3·	2·5	11·	2·75	8	2	3	4·
20	3·5	3·	4·	2·5	[illegible]	[illegible]	9	10	[illegible]	5·
21	4·	3·	[illegible]							
22	3·	4·								
23	4·	4·5								
24	4·									
25	6·									

TABLE II.

Amount of obstruction compared with the virtual section of the River.

Mean velocity of current in feet per second.	1-10th	2-10th	3-10th	4-10th	5-10th	6-10th	7-10th	8-10th	9-10th	
	PROPORTIONAL RISE OF THE RIVER IN FEET.									
1	·0157	·0377	·0697	·1192	·2012	·3521	·6780	1·6094	6·6389	Ordinary Floods.
2	·0277	·0665	·1231	·2108	·3518	·6208	1·1955	2·8378	11·7058	
3	·0477	·1144	2118	·3618	·6107	1·0687	2·0580	4·8850	20·1504	
4	·0760	·1822	·3372	·5759	·9719	1·7008	3·2755	7·7750	32·0720	
5	·1165	·2793	·5168	·8782	1 4895	2·6066	5·0202	11·9160	49·1535	Violent Floods.
6	·1558	·3736	·6912	1·1807	1·9925	3 4868	6·7154	15·9398	65·7518	
7	·2078	·4983	·9221	1·5750	2 6578	4 6511	8·9578	21·2626	87·7080	
8	·2578	·6423	1·1884	2·0299	3 4255	5 9947	11·5454	27·4012	113·0422	Unusually violent Floods.
9	·3359	·8054	1·4903	2·5566	4·2956	7·5172	14·1777	34·3616	141·7541	
10	·4119	·9877	1·8726	3·1218	5·2680	9·2190	17·7557	42 1440	173·8440	

EXAMPLE.—The breadth of the Thames is 926 feet. The sum of the waterways, old London Bridge was 236 feet. The amount of obstruction, therefore, was about ·75 of the entire section; so that a velocity of 3½ feet per second would give a fall of nearly 4·75 feet, agreeing with the actual result.

TABLE III.

Table of effects of running water on Soils.

Velocities. Inches per second.	*Velocities.* Miles per hour.	*Effects.*
	0·170	will work upon fine potter's clay.
6	0·340	will lift fine sand.
8	0·454	will lift sand, coarse as linseed.
12	0·683	will sweep along fine gravel.
24	1·363	will roll rounded pebbles 1″ in diameter.
36	2·045	sweeps angular stones the size of an egg.

N. B.—The velocity at the bottom must be found for comparison with this table.

TABLE IV.

Table of velocities due to certain heights of head-water or afflux.

Height of Afflux. Feet.	Inch.	*Velocity per second.* Feet.	*Remarks.*
0	1	2·30936	
0	2·	3·2659*	* Sweeps angular stones, the size of eggs.
0	3	3·5650	
0	4	4·6186	
0	5	5·1640	
0	6	5·6569	
0	7	6·1101†	† Probable velocity of floods of Jumna Agra, where the bed has been deranged to the depth of 23 ft. Large volumes of water are required to produce this effect.
0	8	6·5320	
0	9	6 9282	
0	10	7·3029	
0	11	7·6942	
1	0	8·0000	
1	3	8·9443	
1	6	9·9797	
1	9	10·584	
2	0	11·314‡	‡ Scooped sand to depth of 23 feet.
2	3	12·028	
2	6	12 649	
2	9	13·266§	§ Scooped out a gravel bed under Smeaton's Hexham Bridge, on the Tyne, by some account.
3	0	13·856	
4	0	16·000	
5	0	17·889‖	‖ Mr. Smeaton himself said 5 feet head-water.
6	0	19·596	
7	0	21·166	
8	0	22·627	
9	0	24·000	
10	0	25·298	

TABLE V.

Natural Cotangents to Radius 1.

Deg.	*Cotangents.*	*Deg.*	*Cotangents.*	*Deg.*	*Cotangents.*
1	57·28996	31	1·66428	61	0·55431
2	28·63625	32	1·60033	62	0·53171
3	19·08114	33	1·53986	63	0·50952
4	14·30067	34	1·48256	64	0·48773
5	11·43005	35	1·42815	65	0·46631
6	9·51436	36	1·37638	66	0·44523
7	8·14435	37	1·32704	67	0·42447
8	7·11537	38	1·27994	68	0·40403
9	6·31375	39	1·23490	69	0·38386
10	5·67128	40	1·19175	70	0·36397
11	5·14455	41	1·15037	71	0·34433
12	4·70463	42	1·11061	72	0·33492
13	4·33147	43	1·07237	73	0·30573
14	4·01078	44	1·03553	74	0·28674
15	3·73205	45	1·00000	75	0·26795
16	3·48741	46	0·95569	76	0·24933
17	3·27085	47	0·93251	77	0·23087
18	3·07768	48	0·90040	78	0·21256
19	2·90421	49	0·86929	79	0·19438
20	2·74748	50	0·83910	80	0·17633
21	2·60509	51	0·80978	81	0·15838
22	2·47509	52	0·78128	82	0·14054
23	2·35585	53	0·75355	83	0·12278
24	2·24604	54	0·72654	84	0·10510
25	2·14451	55	0·70021	85	0·08749
26	2·05030	56	0·67451	86	0·06993
27	1·96261	57	0·64941	87	0·05241
28	1·88073	58	0·62487	88	0·03492
29	1·80405	59	0·60086	89	0·01745
30	1·73205	60	0·57735	90	0·00000

TABLE VI.

Natural Versed Sines to Radius 1.

Deg.	*Versed sines.*	*Deg.*	*Versed sines.*	*Deg.*	*Versed sines.*
1	·00015	31	·14283	61	·51519
2	·00061	32	·15195	62	·53059
3	·00137	33	·16133	63	·54601
4	·00244	34	·17096	64	·56163
5	·00381	35	·18085	65	·57738
6	·00548	36	·19098	66	·59326
7	·00745	37	·20136	67	·60927
8	·00973	38	·21199	68	·62539
9	·01231	39	·22285	69	·64163
10	·01519	40	·23396	70	·65798
11	·01837	41	·24529	71	·67443
12	·02185	42	·25686	72	·69098
13	·02563	43	·26865	73	·70763
14	·02970	44	·28066	74	·72436
15	·03407	45	·29289	75	·74118
16	·03874	46	·30534	76	·75808
17	·04370	47	·31800	77	·77505
18	·04894	48	·33087	78	·79209
19	·05448	49	·34394	79	·80919
20	·06031	50	·35721	80	·82635
21	·06642	51	·37068	81	·84357
22	·07282	52	·38434	82	·86083
23	·07950	53	·39819	83	·87813
24	·08645	54	·41221	84	·89547
25	·09369	55	·42642	85	·91284
26	·10121	56	·44081	86	·93024
27	·10899	57	·45536	87	·94766
28	·11705	58	·47008	88	·96510
29	·12538	59	·48496	89	·98255
30	·13397	60	·50000	90	1·00000

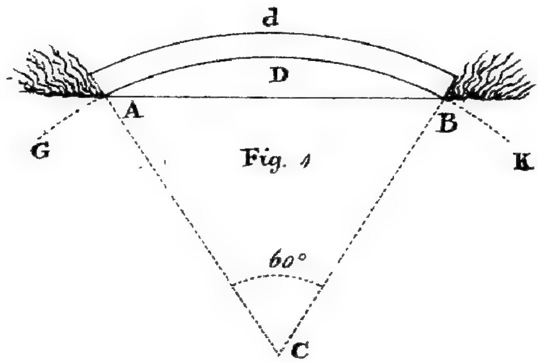


Fig. 1

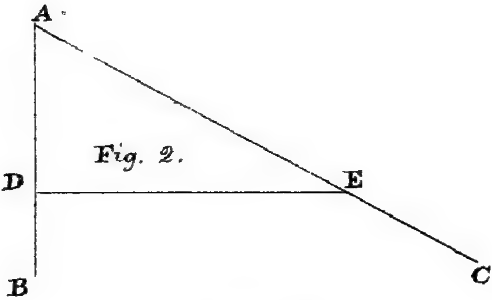


Fig. 2.

Fig. 3.

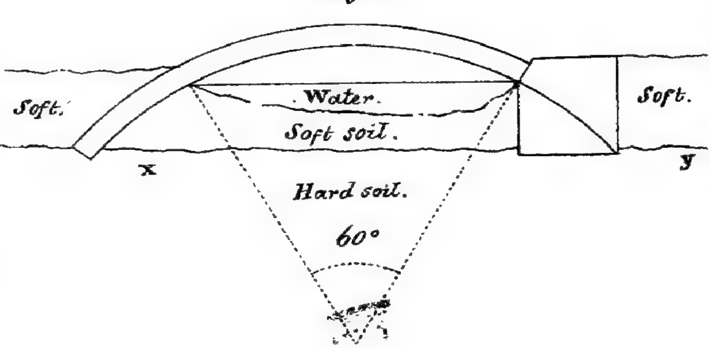


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Fig. 4.

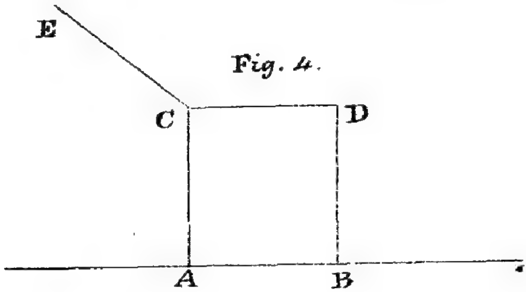

Fig. 5.

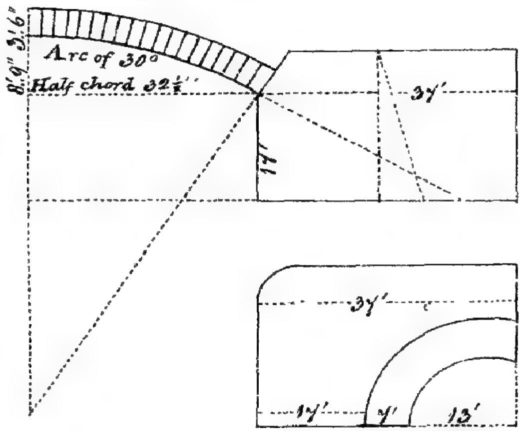

Fig. 6.

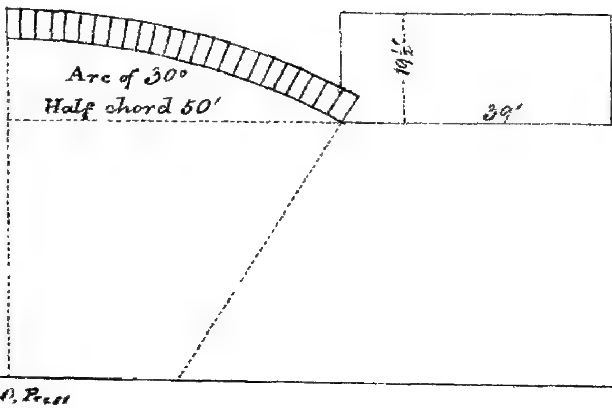

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Fig. 7.

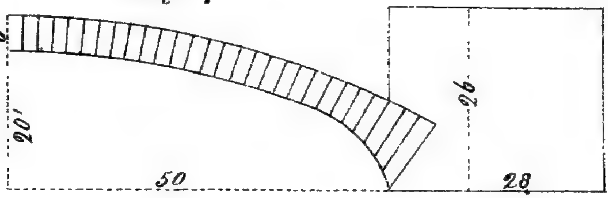
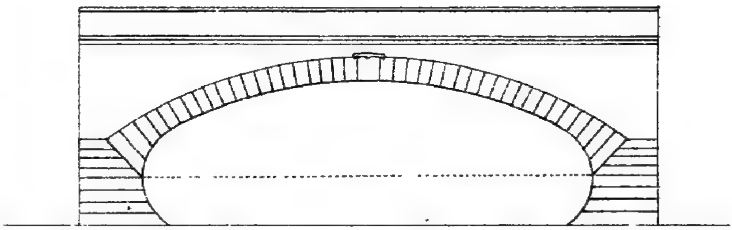


Fig. 8.



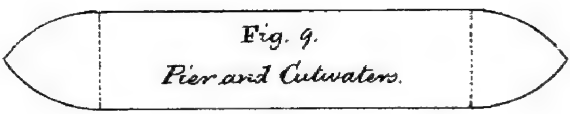


Fig. 9.
Pier and Cutwaters.

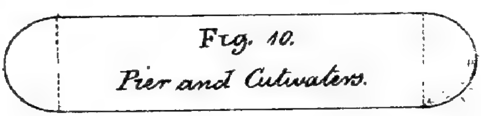


Fig. 10.
Pier and Cutwaters.

S O. Press

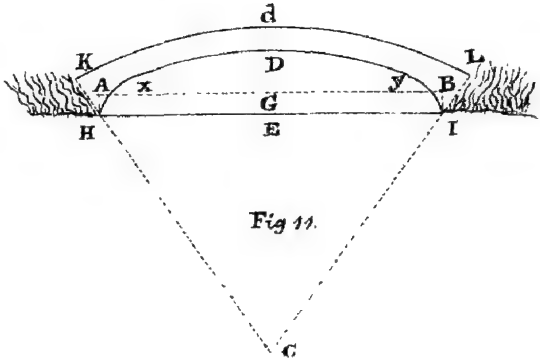


Fig 11.

Fig. 12

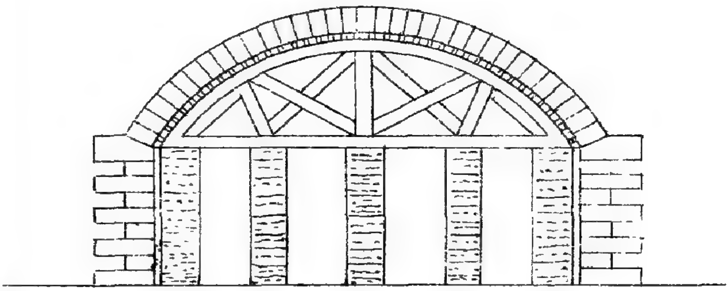
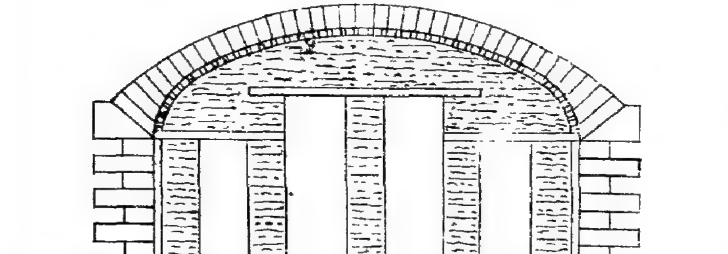


Fig. 13.



J. O. Press.

Fig. 14.

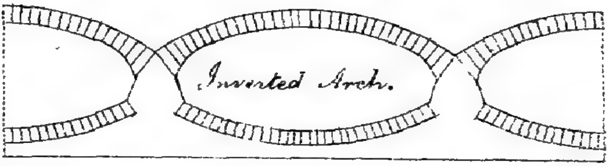
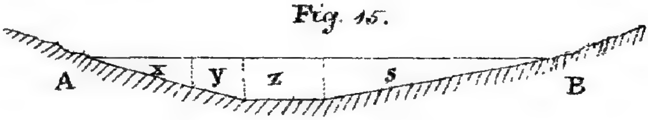


Fig. 15.



S. O. Bracc.

ON THE USE OF WELLS, &c.

IN FOUNDATIONS,

BY

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BENGAL ARTILLERY,

SUPERINTENDENT OF THE DOAB CANAL, &c.

[*From the Journal of the Asiatic Society of Bengal, No.* 88, *April* 1839.]

Piles and caissons being the usual means adopted for foundations in Europe, where the soil and substrata are insufficient, I will venture a few remarks on the system adopted in northern India for the same purpose, especially in the application of hollow cylinders, or wells of masonry. The plan of undersinking wells does not appear to be totally unknown, although it is not practised in England; in fact the only approach to the method upon which I am now about to occupy the pages of this Journal, is exhibited in the works at the Thames Tunnel, at the descent to which Brunel has sunk masonry cylinders "fifty feet in diameter, strongly clamped with iron, &c." the process of effecting which I have no means of describing. Our Upper Indian system, however, is so admirably adapted to the purposes for which it is intended, and so much superior to piling (caissons I put out of the question) that a few remarks, drawn from practical observation, may perhaps induce others, with more information than myself, to attract the notice of English Civil Engineers to a resource well worthy of their attention. The Hindoo religion in deifying the great rivers, and inculcating on its disciples the necessity of constant ablutions, and the rewards held out to those who multiply the shrines and temples on the banks of the sacred waters, have been the cause, in all probability, of the adoption of this system of foundation. In an alluvium so extensive, and so moveable, piles, were they used, would have been found inefficient; the native engi-

neer, however, has no machinery with which piles of a sufficient length could be driven; timber, moreover, at those places where the greatest demand would have existed, could not have been procured without great difficulty, and very great expense. The means of making bricks, on the contrary, were at hand; the labourers required to build masonry and to sink wells were to be found in the neighbourhood; the solidity of structure was withal more pleasing both to the projectors and to the builders; and the idea once adopted, the use of wells not only on the edges of the river, but in all places where the badness of the soil and the height of spring water rendered excavation impracticable, has been acknowledged as the standing resource in the system of hydraulic architecture of Upper India. At Muttra, Bindrabund, &c. where flights of steps or ghâts sweep the whole line of the Jumna within the limits of the respective towns, wells have been extensively used in foundations. The Mussulman buildings at Agra are largely indebted to wells, where the proximity of the Jumna made a depth of foundation necessary; the Doab Canal works have paid equal homage to this admirable native conception, and it is from these works that I shall collect data to enable the reader not only to comprehend the method which is put into practice when wells are used, but also to draw a comparison between their value as the means of foundation, and that of piles and other methods in use elsewhere.

The Chah-kun (from چاه a *well*, and کن the affix from کندن *to dig*,) or well-sinker is a distinct trade scattered throughout the villages of Upper India. Its followers are called into requisition either for sinking new, or for clearing out old wells; in the former case, generally doing their work by contract, at a fixed rate per *háth* or eighteen inches of depth of sinking, and in the latter by the job, or so much for clearing out the well and rendering it fit for use. The expertness of this class of people depends very much, of course, upon practice, and the depth of wells to which the Chah-kun has been accustomed. In a country where the undersinking does not exceed ten or twenty feet, the well-sinkers will profess their inability, or decline to contract for greater depths; in fact

where cylinders are required of from thirty to fifty feet, the Chah-kuns abovementioned would decline the undertaking altogether; the tools and method of using them in such a case, being quite different from what they have been accustomed to.

The tools in use by the Chah-kun consist of the *Phaora*, or common *Mamooti*,* as it is termed in the Ordnance Magazines, and the *Jham*, a large species of *Phaora*. The size of the *Jham* appears to vary according to the fancy of the well-sinker: in the cases which have come under my own observation, the blade has been usually twenty-seven inches wide by thirty-six inches long. The handle, which is short, but similar to that of the *Phaora*, is tied to the blade by a rod of strong iron wire, providing a support and means of attachment for the rope by which the machine is put into operation. The apparatus is a rough looking and barbarous affair, but well adapted to the use to which it is applied, and to the people by whom it is approved of.

In village well-sinking for the use of irrigation, or to supply the inhabitants with water for drinking and other purposes, where the supersoil is tenacious, and resting upon loose strata, in which the springs are found, it is usual to excavate through the upper soil down until water is reached; a ring of timber adapted to the thickness of the walls of the cylinder is then placed horizontally, upon which the masonry is built to a height of three or four feet above the surface level of the country; as the masonry advances, the outer surface is rubbed over with mortar, and the whole is allowed to obtain a moderate degree of induration by remaining untouched for at least ten days; at this period the Chah-kun, or well-sinker's aid is put in requisition. In the earlier stage of the proceedings, the Chah-kun carries on his work very easily, it is only when the cylinder has reached to a depth beyond that of himself, that the tedious and difficult part of his labors commences. After descending the well, and

* Query.—Whence this word?

having in the first instance fixed a string and plummet to the top so as to secure a regularity in the depression, he commences by removing the soil from the centre, and then from the four sides respectively; the soil is brought up to the surface in baskets, and the Chah-kun at the top is in sole charge of the plummet and its movements. For the first three or four feet of sinking there is little fear of accident, and little trouble; in fact, up to this point I have frequently employed common laborers, who, with a little care and superintendence, have done the work as efficiently as an experienced well-sinker. On the application of the *Jham* (vide supra) the top of the cylinder is loaded with logs of wood and heavy articles that may be at hand; a fork-like prop with a pulley is fixed in the ground, so that the rope which runs over the latter, and to which the *Jham* is fixed, should run centrically over the well; the Chah-kun then descends with the *Jham*, and with his hands and feet (for the natives use both with equal facility,) forces the instrument into the soil until it gets properly loaded, when it is drawn up, the contents removed, and the same operation is continued until the work is completed. After the soil has been removed beyond five or six feet below the surface of the water, the Chah-kun's duty is constant *diving*.* I have known them to remain half a minute and nearly a minute under water without any respiration. Each man is relieved at the end of the hour, and in hot weather the cold that they suffer in their escape from the well is severe to a degree; large fires are kept burning for them to recover themselves at, and a liberality on this point is one of the chief agreements between the well-sinker and his employer. In the cold season the annoyance from change of temperature is infinitely less, and the people themselves have often assured me that they could in this weather do twice the quantity of work, and with one-half of the labor to themselves, than they could do when the weather is hot, and when the evaporation was rapid.

* In very deep wells, where the *neemchuk* exceeds twenty-five feet from the water's surface, the *Jham* is worked by long poles fixed to the handle, and the work is most tedious.

In describing the process required for the sinking of one well for common village purposes, we have only now to shew how the application of a number of these wells in conjunction can be turned to account for the purposes of securing a good foundation; for this purpose I shall give plans and sections of some of the works on the Doab Canal, explaining the method adopted in these works, and also shew how, under different circumstances, the same plan of foundation has been used with equal effect.

The course of operations depends on whether the wells used in foundation are placed close together, or at a distance. For piers of bridges with extensive waterway and heavy superstructure the former is usually adopted; in other cases, the wells are placed four feet apart, and connected together by masonry arches, upon which the wall, pier, or building is constructed.

In Canal works, however, it is often an object to obtain a running line of wall for foundation unbroken by divisions or points of separation, through which the substrata, when, consisting of a loose sandy soil, might escape, especially where there is a head water with springs opposed to it. In locks or descents, for instance, constructed in sand, where the subsoil in addition to its own natural spring water has that of the Canal to act upon the flooring of the lower chambers, there is a considerable tendency to the removal of the sand under these lower floorings, which seriously affects the stability of a work, and is only to be provided against by enclosing all the subsoil in continuous lines of foundation. I shall hereafter describe a remedy invented by Col. John Colvin, C. B., of the Engineers, formerly Superintendent of the Delhi, and Superintendent General of Canals; but in the meantime it is evident that where wells or cylinders are used, the continuity of a wall is imperfect under any circumstances; for place them as close together as possible, there is still a separation—the curtain so much desired is wanting. The methods adopted by me in the two cases, first, where wells are sunk *close together*, or leaving a space of six or eight inches, which is the least that can be

safely given, and, secondly, when at a greater distance apart, are these—piles, and as the English engineers now term it, *concrete* (an article which, I may observe in passing, has been in use in Hindoostan from time immemorial); the former in the works on the Doab Canal varying from sixteen to five and a half feet in length, and the latter laid in as deeply as possible between the piles, and allowed to stand for some days to settle and indurate. The piles are made of young Saul trees *(Shorea robusta)* cut in the forests in the northern slope of the Sewalik hills, in the Deyra Doon; or when only five and a half feet long, of the species of rafter called by the natives *Kurri*, the smaller sort averaging from ten to twelve feet long and three and a half inches square, sawed out of Saul timber in the forest, and imported in immense abundance into the plains swung on the back of bullocks by the Bunjáras, a class of people who lead a roving life, employing their cattle in this species of work. The concrete consists of *kunker*, an alluvial lime rock peculiar to India—of stone boulders from the river broken into fragments—the *gutta* or refuse of lime kilns, mixed with a proportion of cement, consisting of two or three parts of *soorkhee*, or pounded brick, and one part of the best stone lime thrown in and well mixed together with a pole, sharp at one end and blunt at the other; the former to stir up the mixture for a certain time, and the latter to ram it down until it is properly placed in position.

The figures in Plates 1 and 2 represent these methods in detail, with the *neemchuk* and tools used by the well-sinkers; and in Plate 4, which is a plan and section of falls and locks as constructed on the Doab Canal, the application of both will be easily recognized.

The depth to which a cylinder of six feet in diameter can be sunk during the day by one party of well-sinkers through a sandy stratum as far as ten feet, varies from two and a half feet to four inches. It is desirable when the well has to be sunk to this depth only, to expedite the depression of the three or four last feet as much as possible, so as to get the cylinder to its full depth, without leaving it during

the night, and allowing the loose soil to settle round it, and give it a firm embrace. It is very difficult at times to free the sides of the cylinder from the hold which the sand has in this case upon them, but even with a very heavy weight applied to the top half a day may be expended in this way, without getting the well to move at all—a remark equally applicable in pile-driving through sand, where the advantages of driving the last pile that is driven during the day to its full depth, is well known. I have seen a pile, length twenty feet and diameter eight inches, which has been driven ten feet on the previous evening, resist on the next morning the weight of the pile engine for forty successive strokes—the weight of 250lbs. falling through a space of ten feet, the head of the pile becoming perfectly shattered and useless. The following table will give an approximation to the expense of sinking cylinders of the abovementioned diameter to a depth of ten feet, and although the difficulties attending the operations from which this table was formed were greater than would be generally experienced, a very tolerable idea of the expense of well-sinking will be exhibited.

Soil, sandy, mixed with clay, but free from stones or kunker; full of springs, with the canal head water ten feet above the point at which the cylinder commenced sinking; outer diameter of well six feet, and in some instances eight feet, and inner diameter four and six feet respectively; machinery employed night and day in keeping the water down to the level on which the wells were built; windlass used with the *Jham*; period of operation between January and May.

Well Sinkers.	Windlass men.	Laborers.	Carpenters.	Smiths.	Sundries. Rope, Iron. Leather, Oil, &c., &c.	Expense in labor.	Total expense.	Length of well or cylinder sunk in running feet.
					Rs. A. P	Rs. A. P.	R. A. P.	
1267	1688	358	30	30	10 10 2	439 5 10	450 0 0	202¼

Or average per running foot Rs. 2 : 0 : 4

The cost of building a cylinder of the above diameter, viz. 6 feet, and 10 feet high, may be thus—

Laborers,..	9	0	0
2050 bricks, 12 × 6 × 2 ..	10	4	0
16 maunds stone line, ..	6	0	0
Neemchuk or curb, ...	2	12	0
Total cost, ..	28	0	0, or per foot 2 : 12 : 10

giving the average cost of well-sinking, using a cylinder of six feet in diameter and carried to a depth of ten feet at Rs. 4 : 13 : 2 per running foot. In the above table, however, as I before remarked, the items are dependent on difficulties which in well-sinking from a plain surface—from the level of a garden for instance—would not be met with. In wells situated in this way, and of similar dimensions in every respect to those upon which our data are formed, the expense varies at from three rupees six annas to four rupees per running foot, the difference depending on the cost of laborers—the price of materials remaining constant. The masonry of well-building I have generally found to vary from eighteen to twenty rupees per 100 cubic feet.

In wells of from sixteen to twenty feet depth the expense per running foot has been found to vary from Rs. 7-8 to Rs. 8-8, using the cylinder above noted ; to a greater depth, however, they require to be of larger dimensions ; but it would be interesting to discover the progressive advance in expense on each ten feet of well-sinking ; it would possibly advance in a series with a common multiplier of two, leading to the following table as an approximation—the upper line representing depths of cylinder in feet up to thirty, the second the cost per running foot, and the lower the actual cost of well at each depth as noted in the upper line.

10 feet.	20 feet.	30 feet.
4 Rupees.	8 Rupees.	16 Rupees.
40 Rupees.	160 Rupees.	480 Rupees.

The two first columns are formed on my own practical observation, and the third is from the cost of village wells, extracted from the statistical notes of the Revenue Surveyors in the upper portion of the Doab, *plus* the expense of undersinking the first sixteen or twenty feet, which in village wells is generally built up.

It must be recollected that the cylinders are supposed to be undersunk from the commencement through a sandy soil, and with spring water at the surface—as must usually occur in foundations where the application of them for that purpose would be necessary. The cost of village wells, which although thirty or forty feet deep are only undersunk on reaching the springs, is proportionably less.

With reference to the value of obtaining a connected curtain, or line of running wall in foundation, where the interference of spring water renders undersinking necessary, Colonel Colvin, C. B. of the Bengal Engineers, proposed a plan of sinking square masses or parallelopipedons of masonry, piercing these masses by wells, as represented in Fig. 1, Pl. 3. The plan succeeded in every respect. In those of from ten to fifteen feet long and four feet wide, undersinking to a depth of ten feet in sand mixed with small shingle was carried into execution with perfect success in the foundations of the dam over the Somóe river. Water was, at the point where the dam had to be constructed, immediately on the surface; the object of the dam was to retain the supply of water to a considerable height to throw it into the Delhi Canal, and maintain a supply during the dry months. Circular wells were objectionable for the reasons which I have before explained, and it was a desideratum to get such a foundation, that the head pressure of water should affect the leakage *under* the dam as little as possible. Fig. 1, Pl. 3, will explain the method adopted, the spaces between the boxes on the first row being covered by those in the second line.

The method put into practice in sinking these masses is similar to that in cylinders, but greater care is required in regulating the operation of the well-sinkers, so that the mass may be lowered equally. The curb, or *neemchuk*, is a platform of wood equal in size to the base of the masonry, with round or oval holes cut for the wells, as shewn in Fig. 1, Pl. 3. I have used these masses in lengths of twenty-one feet, by four feet wide, to a depth of ten feet, with perfect success, giving three wells in each. I should however limit the dimensions to fifteen feet by four feet, with two wells elliptical, five feet by two and a half each, which with proper care will be sunk to a depth of ten feet through sand without any difficulty. There appears no reason why a whole foundation of a work within certain limits might not be sunk in this way. It is often a difficult matter to obtain foundation for a bridge with an arch of twenty feet span, where the soil is sand, although the drainage is not liable to freshes or any violence of current. A bridge of this sort, with a roadway of fifteen feet, would require a mass in superficial area equal to twenty-eight feet by eighteen, to a depth say of from six to ten feet, which would be quite sufficient, even if the mass rested on sand. There is no reason why, by piercing this block with cylinders, the whole might not be lowered, and a foundation obtained of infinitely greater security, and certainly not at greater expense, than any of the methods now adopted.* The greater advantage however of this plan over others, is its simplicity; all the apparatus, machinery, &c. of piling are thrown aside; a few carpenters procurable at every village, and masons to be had without difficulty, with some Chah-kuns to sink the mass, are all that is required.

Where stone in slabs is to be procured, a method is adopted by the natives of forming what they call *kothis*, that

* Since the above paper was written, bridge abutments with their wings in one mass have been built and undersunk, on the Delhi Canal: and on the Ganges Canal works, masses of masonry for the purposes of foundation, measuring in base 32 feet square, have also been undersunk.

is to say a caisson without a bottom. The stones are clamped together, as shewn in Fig. 3, Pl. 3, by wooden clamps; these boxes are undersunk in the same way as the cylinder, but the form is inconvenient, and the difficulty of sinking them greater than either the cylinder or the block above described. The circular form as regards friction alone, offers a much smaller surface than the square; but the square block of Colonel Colvin has great weight to assist its descent, which the stone *kothi* has not. In the foundations of the bridge over the Caramnassa river, laid down by Nana Farnavis, these *kothis* were extensively used. These foundations when laid bare for the ulterior operations appear to have extended across the bed of the river on a width of sixty feet, the *kothis*, which were fifteen feet square, being placed close together, and sunk through sand to a depth of twenty feet. The reader is however referred to Vol. 3 of the Gleanings in Science, in which Mr. James Prinsep has given a most interesting detail of the Caramnassa bridge operations. I may however remark that the *kothis* in question, after being sunk are filled with *grouting*, or a mixture of lime, kunkur, &c. (concrete) forming an artificial conglomerate, upon which the superstructure is raised. Mr. Prinsep uses the word *dhoka*, in this part of India *ghuttu* is the term usually applied to this species of material. The *jamwat* corresponds with the *neemchuk* of the northern Doab.

Another species of *kothi*, which is also used not only in foundations but in village wells, consists of frames of wood joined together at the angles, as represented in Fig. 4, Pl. 3; this from the want of weight is still more difficult to sink than the one before described; it is however convenient where wood is plentiful, and the soil to be pierced of a light description; they are undersunk precisely in the same way as the common cylinder. In village wells, when the *kothi* is from four to five feet square and the thickness or scantling of the wood used four or five inches, it lasts for many years, and merely requires repair in the upper portion, where its exposure to the atmosphere tends to the destruction of the material.

The *Sundook*, or box, is another, and perhaps the most awkward of all methods to obtain a depth of foundation; it is adopted by the natives, but generally where there are no experienced workmen. The plan and form of this box is represented in Fig. 5, Pl. 3; the size generally about ten feet long by five feet wide, and depth not exceeding five feet. The size of the box being lined out on the ground where it has to be sunk, a pointed timber six feet long, or thereabout, and four inches square, is driven into the ground at each corner, two inch planks are then nailed on the uprights, and the whole made as strong as possible, either by additional uprights on the sides or by transoms; the soil is then removed from the inside, and the depression goes on by driving the uprights down with mallets, as fast as the removal of the soil from the inside will admit of it. As may be supposed the frame work is liable to disarrangement in every way; when sunk to its full depth the interior is filled with *grouting* (concrete) and the heads of the corner piles or uprights sawed off. These foundations are allowed to stand for a year at least before the superstructure is commenced.

Piling as the means of foundation, appears as far as my observation has gone, to be totally unknown throughout Hindusthan. I have never met with it under any form, or under any modification. The fact is, that labour is so cheap in India, that it is less expensive to adopt any means for purposes of this sort with *manual* labor, than with *machinery!* That the value of the latter would in the course of time be most justly appreciated, there can be no doubt; but the philanthropy of the existing generation has not arrived at that point which would lead the builder of a Ghat or of a Musjid to *experimentalize*, when he has before him a secure and well authenticated method of operation.

To recur to the wells or cylinders, it is usual to fill them with *grouting* of lime, kunkur, and broken brick, so as to make a solid mass of the whole for the superstructure to rest upon. This may be necessary where the wells are sunk to a great depth, and where the superstructure is of great

weight, but in other cases the value or necessity of such an arrangement may be doubtful. The wells used by me have never exceeded twenty feet in depth, the greatest number only ten. From their position they are in some instances liable to be undermined by a current setting in upon them when supporting a revetment or line of ghat, or in the case of locks from under-currents, and I have invariably filled the cylinder with large masses of kunkur, or vitrified brick, *without* cement of any description, on the principle, that if the stratum upon which the cylinder rested was at all acted upon or undermined, the masses of loose material would sink and occupy the space caused by the action of the water below ; in fact the hollow cylinders are quite sufficient to support the superstructure placed upon them, the internal space may therefore be well occupied by any means to counteract danger from the vagaries of the stream.

The varieties of lime procurable between the Himalayas and Delhi are peculiarly favorable to hydraulic works. The beds of the rivers which drain the valley of Deyra, situated between the parent mountains and the Sewaliks, are loaded with boulders of lime rock ; the shingle strata of the Sewaliks themselves contain also a plentiful supply ; these, with the main outlets of the Jumna and Ganges provide lime for all the upper portion of this Doab. The boulders are collected and either burnt on the spot, are carried to the works ; in the former instance the cost of the material from the Hills to points between them and the town of Saharunpoor averages as follows :—

		R.	A
Cost ℔ 100 maunds at the Kiln from 8 to 10 Rs. say,		10	0
Carriage of ditto to the works at ℔ md. 3 to 3½. As. say,		21	4
Custom levied at the Ghats or passes in the Sewaliks, say,	½ an anna ℔ bullock load	2	2
	Total cost ℔ 100 mds.	34	

Although this lime is in many cases pure, *i. e.* crystalline carbonate without admixture—and by selecting the boulders

previously to burning may be obtained sufficiently pure for the whitest stucco, or white-wash—the article from the kilns is much adulterated with clays and metallic oxides, arising from the varieties of lime rock which are thrown into the beds of the rivers. With the use of soorkhee therefore (or pounded brick) this lime makes an admirable water-cement. In wells and foundations I have generally used it in the following proportions :—

2 parts soorkhee
1 ditto lime, or
5 maunds, or 400lbs. of soorkhee
$1\frac{3}{4}$ maunds, or 140lbs. of stone lime,

mixed well together in a mortar mill before it is used. Above the level of the water I have found it advisable to reduce the quantity of soorkhee ; the cement in this case consists of

$1\frac{1}{2}$ parts of soorkhee, or $3\frac{3}{4}$ maunds
1 ditto of lime, or $1\frac{3}{4}$ maunds.

The lime in fact is so good, that where well burnt bricks are used, bad masonry is entirely out of the question ; the builder cannot help himself, and for this portion of his duty deserves no sort of credit whatever.

This stone lime is used universally on the Doab Canal from the point where it leaves the Jumna to Rampoor, a town twelve miles south of Saharunpoor ; from this the marles and kunkur limes of the districts come into use, although the stone lime is brought into requisition on a smaller scale for arch-work as well as parapets ; and in plastering masonry works it is solely used.

The marle, or earth lime as it is usually called, is in much greater abundance on this line than kunkur. When extracted from the quarries or pits, it is perfectly soft and friable, in which state it is kneaded up into round balls about two or three inches in diameter, which are placed in the sun to dry, previously to their being burnt in the kiln. The marles

differ very much in quality, but all of them make an admirable water-cement. That from Jussooe, a village on the Khadir of the Hindun river is the most approved of, and is delivered on the works within a circle of ten and fifteen miles at about twelve Rupees per 100 maunds. These marles are full of fresh water shells of species now existing in all the tanks, jheels, and rivers of the country; those of *Melania*, *Lymnæa*, and *Planorbis* being in the greatest abundance.

The kunkur limes are more numerous in the southern districts of the Canal, they also make a good water-cement, but contain no remains of fresh water exuviæ.

Near a village called Hursoroo, twenty-five miles to the south-west of Delhi, a very superior kunkur lime is procured—the formation itself is intermediate between kunkur and marle, but the position of the quarries from which it is excavated is similar to that in which all this material is procured, in a low tract of country, the site in all probability of a lake or jheel now filled up.* The same fresh water shells as are found in the marles to the eastward of the Jumna, are very numerous in the Hursoroo lime. It is exported in large blocks, and is sold in Delhi at from twelve to fifteen Rupees per 100 maunds. The cost after burning varies from twenty-five to thirty Rupees per 100. This lime for a water-cement is very far superior to any lime that I have met with. When calcined it is of a very light color, and might be mistaken for the stone lime of the Northern Division. In the locks and works on the Doab Canal appended to them, at Shukulpoor, Sikrani, and Jaoli, in the southern district opposite Delhi, nothing but Hursoroo in the following proportions has been used in the superstructure :—

* Hursoroo is situated on a nullah which rises in the small hills near the Kootub Minar, and flows into the south-west end of the Furruknuggur jheel. The town of Hursoroo, or as it is more commonly called Hursoroo ghurree, is about two miles from the jheel.

1 part of Hursoroo,*
1½ ditto of Bujree,

and in the neighbourhood of Delhi the use of pounded brick, or soorkhee, has been almost entirely superseded by that of Bujree.†

The sand stone, which is an attendant upon the great Quartzoze formation of the ridge upon which Tughlukabad, the Kootub Minar, and old and new Delhi stand, varies from compact and crystalline, to a loose and friable rock; in this latter case it consists of an agglutination of minute angular fragments of quartz, with, in some cases, a red oxide of iron in such abundance as to give the strata quite a peculiar character; in other cases the oxide is wanting, and this friable rock is of a light color. For roads and other purposes these varieties of the sand stone are much in request, and amongst the natives obtain the name of *Bujree*. Nothing could be a better substitute for soorkhee, than the substance in question. The presence of the iron oxide is in every way favorable to its value in hydraulic works, and the sharpness of the particles of which it is composed renders it an admirable mixture with lime for plaster or stucco. In this form it stands the effect of the climate much better than soorkhee or river sand. In the proportion of one part of

* The following is the detail of proportions used in the cement at these works, and as they were built in 1834-35, a sufficient time has elapsed to judge of the durability of the masonry, no repair of any description having taken place up to this period.

Foundations including Floorings, &c.	Hursoroo Lime, ...	1	part.
	Earth lime, ...	2	,,
	Bujree, ...	2	,,
Superstructure, ...	Hursoroo Lime, ...	1	,,
	Bujree, ...	1½	,,
Plaster, ...	Hursoroo Lime, ...	1	,,
	Bujree, ...	1	,,
Sundulla or outer thin coating given to the plaster, as a finish.	Stone Lime, ...	8	,,
	Soorkhee, ...	1	,,

† This has I believe been the case in the Delhi works for many years.

Hursoroo lime to one part of Bujree, mortar laid on with a float, as is used in sand, may be considered very far superior to it, and with a much better appearance than that practised by the natives, under the tedious process of beating with the *thappa*. This Bujree is now universally used on the Doab Canal works, at all points at which it can be delivered under eight rupees per 100 maunds, this being the maximum rate of pounded brick. For water-cement the Hursoroo lime with a proper proportion of this red Bujree may perhaps be considered as superior to all others attainable in this part of the world.

In conclusion :—the Saul *(Shorea robusta)*, which is found in great quantities in the Deyra Doon, and especially on the northern slope of the Sewaliks, is the wood chiefly used on the Canal works for piles, rafters, lock-gates, sleepers, windlasses, vanes, &c. &c. The Sissoo *(Dalbergia sissoo)*, Toon *(Cedrela toona)*, Siriss, *(Acacia serissa)*, are used in doors, door-frames, mill machinery, &c. For handles of tools, pickaxes, phaoras, arbors of mill wheels, &c. the *Acacia, catechu (*or *Kyr)*, the wood from which the *Terra Japonica* of commerce is procured, and which grows in great abundance in the forests south of the Sewaliks, and the *Acacia arabica (*or *Keekur)*, are chiefly in request. For Neemchuks of wells the natives always select the Dhak or Plass (*Butea frondosa)*, and if this is not to be had prefer the wood of the *Ficus Indica, F. Bengalensis, Bombax Malabaricus (Semmut,* or cotton tree) ; the Horse radish tree (the *Hyperanthera morunga of* botanists) is also used :—in fact, all the light woods which are valued as floats for rafting timbers are considered better than others for the curbs of wells. The Neem *(Melia azadirachta)* is a useful wood for small rafters, door frames, &c. from being less liable to the attack of white ants. A variety of Pine *(Pinus longifolia)* which grows in extensive forests in the Sewalik mountains is held in no esteem by the natives ; it is good for making light boxes and common furniture, but in attempting to bring it into use on the works I have failed ; very capital tar, however, is procured from it, as well as turpentine.

To Mr. acting Sub-Conductor John Pigott, Overseer of the northern division of the Canal, under whose charge the greater part of the works from which the above data on well-foundations have been formed, I am indebted for much valuable aid: his introduction of the windlass in sinking wells has not only led to a great saving of expense, but added much to the facility of depressing them. His general quickness, moreover, at resources under sudden and unexpected difficulties, which can only be appreciated by those who have seen the effects of the *Raos,* or mountain torrents in the rainy months, is deserving of the best acknowledgment that I can offer him.

Northern Doab, May 8th, 1833.

Jham used in Well Sinking.

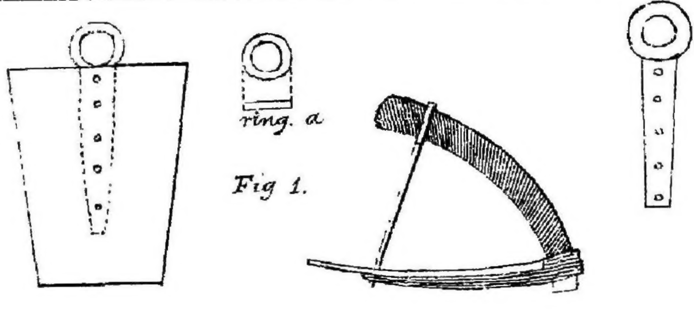
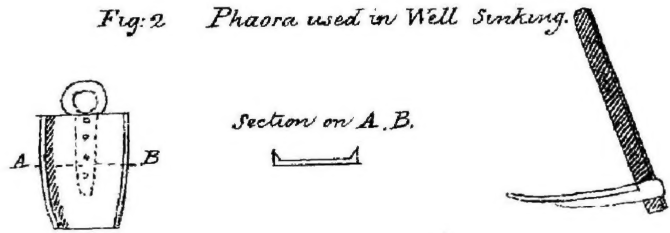


Fig 1.

Fig: 2 Phaora used in Well Sinking.



Native method of working the Jham.

Fig: 3.

Canal method of working the Jham.

Fig: 4

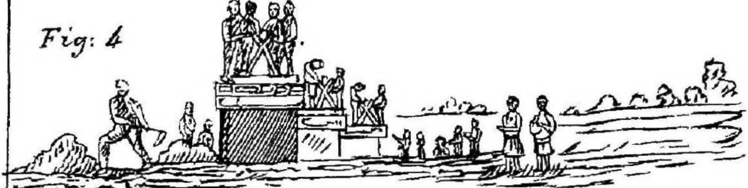


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Plate 2.

Wells with Intervals. Wells without Intervals.

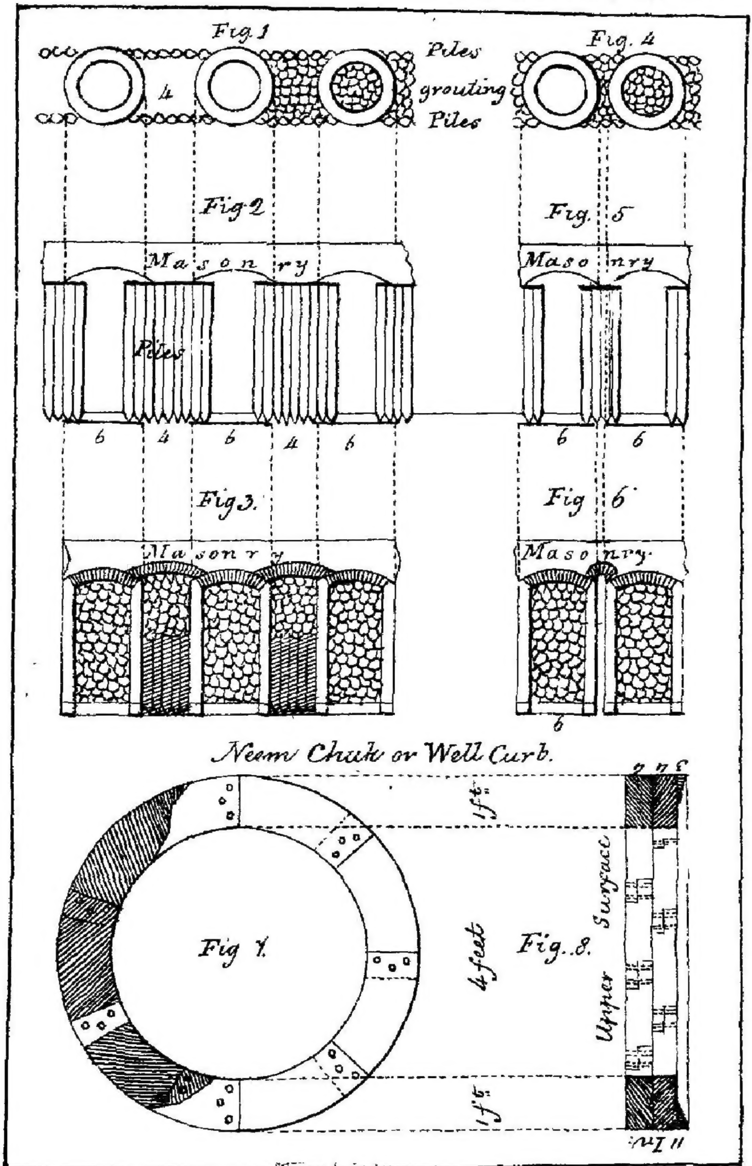

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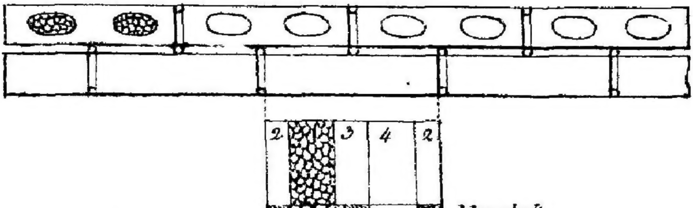
Plate 3

Fig: 1.

Plan of the Colvinian Box Foundation, as practised in running lines. with a section of one of the boxes shewing the Wells.



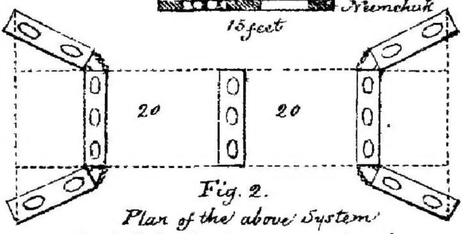


Fig. 2.
Plan of the above System adapted to a bridge with 40 ft. Waterway

Fig. 3
Stone Kothi

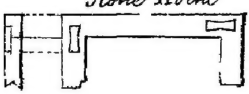


Fig 5
Sundook or Box

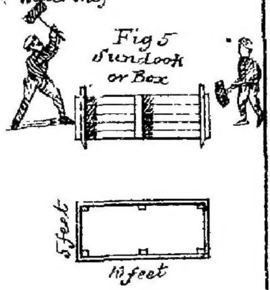
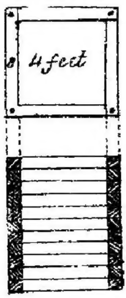


Fig: 4
Wooden Kothi



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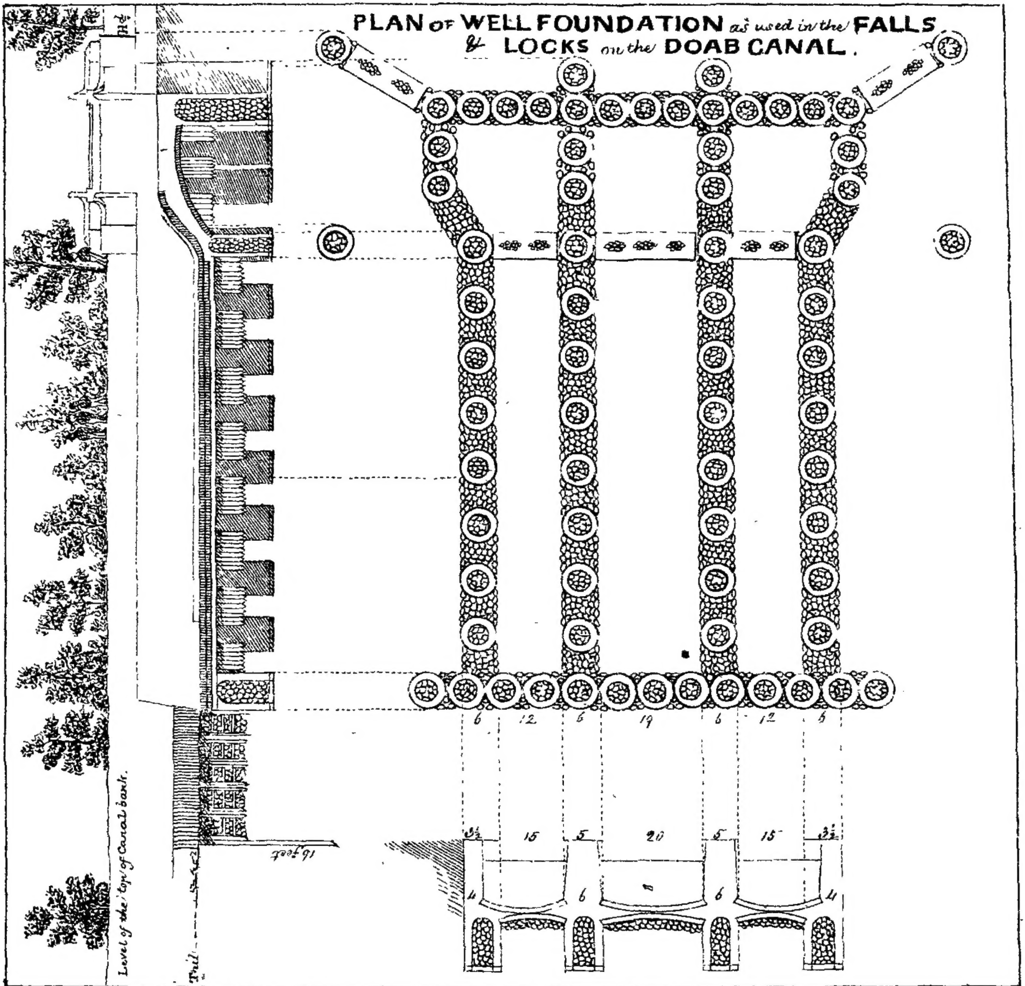

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